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Kodaikanal Observatory.

BULLETIN No. XXIX.

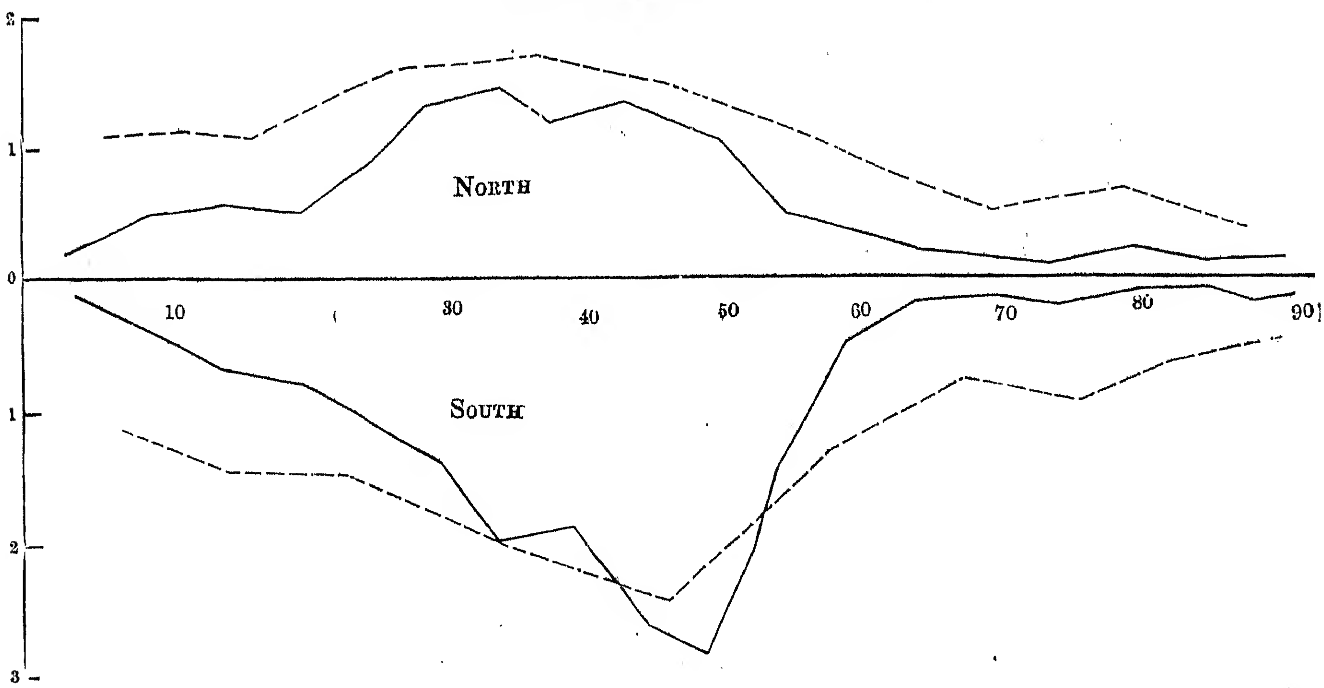
SUMMARY OF PROMINENCE OBSERVATIONS FOR THE FIRST HALF OF THE YEAR 1912.

THE detailed lists of prominences recorded at Kodaikanal and published in a series of bulletins ending with No. XXVIII, will henceforth be discontinued, and a résumé of the observations will in future be issued half-yearly. This will include full descriptions of any remarkable phenomena observed or photographed, and in addition to the summary of the observations at the sun's limb the results will be given of a study of the prominences projected on the disk as hydrogen absorption markings.

The general distribution of the prominences in latitude during the six months ending June 30, 1912 is represented in the accompanying diagram. In this the full line gives the mean daily areas for each zone of 5° of latitude and the broken line the mean daily numbers averaged for 10° intervals. The scale of ordinates represents tenths of square minutes of arc for the full line and numbers for the broken line. Both are corrected for partial or imperfect observations, the total of 173 days of observation being reduced to 159 "effective" days.

MEAN AREAS AND MEAN NUMBERS OF PROMINENCES.
JANUARY 1ST TO JUNE 30TH, 1912.

Mean areas—full line.
Mean numbers—broken line.



As is always the case the mean areas show much more marked maxima and minima than the mean numbers, because of the much greater average size of the prominences occurring in the zones of greatest activity. The figure for the mean areas closely resembles that obtained for the previous six months but

there is a general decrease of activity. The strongly marked active zone shown during the latter half of 1911 at + 20° to + 25° has disappeared, there has however been an increase in the zone — 30° to — 35°.

The polar regions show the smallest activity which is nearly constant from the poles to latitude 60° in each hemisphere; the equatorial zone is also a region of small activity extending for a few degrees only on either side of the equator. The zone of greatest mean area is situated in the southern hemisphere between the parallels 45° and 50°, and this position of maximum is the same as was found for the whole of the year 1911.

The total mean daily areas and numbers for each hemisphere are:—

		Areas.			Numbers.
North	..	0·98	square minutes	North	8·8
South	..	1·50	Do.	South	11·2
				On equator	·1
Total	..	2·48	Do.	Total ..	20·1

The areas indicate a decrease of 24 per cent. in the north and 13 per cent. in the south as compared with the second half of 1911, but the numbers do not show nearly so large a decrease. In the following table are given the monthly, quarterly, and half-yearly frequencies as well as the mean heights and mean extent of the prominences; the frequencies are here uncorrected for partial observations. Taking the total number of effective days as 159 the mean frequency for the six months is 20·1 as above, instead of 18·5 as given at the bottom of column 4, a decrease of only 4 per cent. as compared with the corrected figure for the previous six months.

Abstract for the first half year of 1912.

Month.	No. of days of observation.	No. of prominences.	Mean daily frequency.	Mean height.	Mean extent.
				″	°
January	30	856	28·5	29·0	1·03
February	29	604	20·8	28·6	1·00
March	31	569	18·4	28·9	1·13
April	29	501	17·3	26·9	1·09
May	31	455	14·7	27·0	0·99
June	23	218	9·5	30·0	1·11
First quarter	90	2029	22·5	28·8	1·05
Second quarter ...	83	1174	14·1	27·5	1·06
Half year	173	3203	18·5	28·4	1·05

The frequency for the month of January is unusually high and on certain days during this month over 40 prominences were counted, the limb presenting a remarkable appearance with prominences in all latitudes, including the polar regions where they were numerous though of small size. Such activity is noteworthy considering that this month was the first entirely spotless month which has occurred since the year 1901, according to the Kodaikanal records.

Mean height.

The average apparent height of the prominences, 28″·4 for the six months, slightly exceeds that obtained for the year 1911 as well as for the four preceding years; it is remarkable that whilst the mean areas have steadily diminished from 5·4 square minutes per diem in 1908 to 2·5 square minutes in 1912 the mean heights have remained almost constant, varying irregularly from 26″·8 to 28″·4. The mean numbers have also remained sensibly constant over these years so that the reduction of area, synchronising with reduction in sunspot activity, implies a diminution of breadth only or extent on the limb.

The total number of prominences recorded during the 173 observing days which attained an apparent height of 60″ or more was 305, which gives a daily average slightly exceeding that for the two previous years. The month of January was also the most prolific in high prominences since 84 were recorded of 60″ or more in 30 observing days during that month.

No large eruptive prominences were observed or photographed during the period under review. The highest prominence recorded was photographed on June 22 between — 19° and — 27° on the east limb. This was an extensive and nearly detached mass at 10 hours 31 minutes, the highest filaments reaching an altitude of 210 seconds of arc. Owing to unfavourable weather, it was not possible to secure an extended series of photographs, and the few obtained were of poor quality. The prominence appeared to be disintegrating rather rapidly, and at 11 hours 20 minutes the highest part was only 150″ above the limb.

Distribution east and west of the sun's axis.

During each of the eight years since prominence observations were begun at Kodaikanal the eastern hemisphere has shown a numerical preponderance over the western.* The results for numbers and areas during the first half of 1912 are as follows :—

1912 January—June	*East.*	*West.*	E.—W.	Percentage east.
Numbers observed	1669	1528	+ 141	52·20
Total areas in square minutes	194·0	199·6	— 5·6	49·29

Metallic prominences.

Particulars of the metallic prominences observed are given in the following list :—

Date.		I.S.T.		Base.	Latitude.		Limb.	Height.	Elements giving bright lines.
					North.	South.			
		H.	M.	°	°	°		″	
January	21	8	56	1	1·5	...	W	25	Na, Mg, and pFe.
February	29	8	16	2	...	12	E	40	Na, Mg, and pFe.
March	6	8	37	...	...	11	E	60, 30	Na, Mg, and pFe, pTi, pCr, and He (6677).
March	15	8	33	2	7	...	E	15	Na, Mg, and pFe.
March	19	8	47	6	...	52	W	45	Na, Mg.
April	15	8	45	1	...	13·5	W	30	Na, Mg, and pFe.
"	"	8	45	1·5	...	12	W	20	
June	3	8	23	5	...	8	W	15	Na, Mg, pFe, and He (6677).
June	7	8	22	...	...	9	W	40	Na, Mg, pFe, and He (6677).

Only nine prominences of this type were recorded, two in the northern and seven in the southern hemisphere. Most of these were associated with sunspot disturbances and occurred in regions of calcium flocculi. An exception was that of March 19th on the west limb in latitude — 52°. This showed the usual sodium and magnesium lines reversed but no others. The prominence richest in bright lines was that of March 6th in latitude — 11° E. The following lines were recorded :—

λ Rowland.	Origin.	High or low level line according to Fowler.
4924·107	pFe	High level.
4930·486	Fe	
5018·629	pFe	High level.
5167·678 b_4	Mg	
5169·220 b_3	pFe	

* Kodaikanal Observatory Bulletin No. XXVIII.

λ Rowland.	Origin.	High or low level line according to Fowler.
5172·856 b_2	Mg	
5183·791 b_1	Mg	
5188·863	pTi	High level.
5195·113	Fe	
5206·215	Cr—Ti	Low level.
5208·596	Cr	Do.
5227·043	Fe—Cr	
5233·112	Fe	
5234·791	pFe	High level.
5270·558	Fe	Low level.
5276·169	pFe	High level.
5284·281		Do.
5316·790	pFe	Do.
5890·186 D_2	Na	
5896·155 D_1	Na	

This prominence was a brilliant eruptive jet in a group of fainter prominences and appears to have occupied the exact position of a newly forming spot, No. 6977 of the Greenwich numeration. The prominences of April 15 at — 12° W. and — 13°·5 W. were associated with spot group No. 6980 and may be considered as a return of the former since they occurred in the same mass of calcium flocculi which gave rise to both spot groups.

The prominence of June 3 at — 8° W. occurred in a newly-formed spot group, Greenwich No. 6990. This outburst in the same zone of latitude as those described above was however about 40° of longitude in advance of the old disturbance first seen on March 6th. The relative positions of the old and new disturbances are well shown in the calcium spectroheliograms obtained on the last day of May and the first days of June when the old disturbance still persisted as scattered flocculi.

The distribution of the metallic prominences in latitude was as follows :—

	Number observed.	Mean latitudes.	Extreme latitudes.
North	2	4°·2	1°—7°.
South	6	17·1	7—47.

Displacements of the hydrogen lines.

Prominences showing displacements of the hydrogen lines, probably due in most cases to movements in the line of sight, were few in number in comparison with previous years, and the displacements were for the most part slight in amount. The list below includes all the disturbances of this character that were observed :—

Date.		I.S.T.	Latitude.	Line.	Amount and direction of shift.		Remarks.
					Red.	Blue.	
1912		H. M.	°				
January	5	9 15	+ 82 W.	C	Slight.		
,,	10	19	+ 39 W.	C	,,		
,,	22	26	+ 9·5 W.	C	,,		
,,	26	8 15	— 84 W.	C	,,		
February	10	8 26	+ 74 E.	C	,,		
,,	18	8	— 80 E.	C	,,		
,,	23	48	— 82 E.	C	,,		

Date.		I.S.T.		Latitude.	Line.	Amount and direction of shift.		Remarks.
						Red.	Blue.	
1912.		H.	M.	°				
February	27		32	– 11 W.	C	Slight.		
March	5	8	48	– 63 W.	C	,,		
,,	6		37	– 11 E.	C	,,		Metallic prominence (spot No. 6977).
,	15		33	+ 7 E.	C	,,		Metallic prominence.
,,	20	9	50	– 68 W.	C	,,		
,,	23	7	57	– 81 E.	C		Slight.	
April	2	8	37	– 58·5 E.	C	Slight.		
,,	5		52	+ 81·5 E.	C	,,		
,,	8		21	– 78 W.	C	,,		
,,	8		14	– 41·5 W.	C	,,		
,,	8		55	+ 51·5 W.	C	,,		
,,	16		16	– 12 W.	F	3Å		Associated with spot group No. 6980.
,,	20		35	– 70·5 W.	C	0·5Å		
May	9	8	37	+ 86·5 W.	C		Slight.	
,,	12		10	– 72 E.	C	Slight.		
,,	22		19	– 79 E.	C	,,		
June	1	8	29	– 8·5 W.	C	,,		
,,	3		23	– 8·0 W.	C	1Å		Associated with spot No. 6990.
,,	23	10	6	– 70·5 W.	C	Slight.		

It is to be noted that out of twenty-six disturbances twenty-four gave shifts towards the red end of the spectrum and only two towards the blue. It is also remarkable that a large proportion (fourteen) were met with in high latitudes between the limits 68° and 80°, only seven being observed in low latitudes between 7° and 17° and five in middle latitudes between 39° and 63°. Sixty-nine per cent. of the whole number were in the southern hemisphere and the largest displacements were associated with sunspot disturbances.

The preponderance of displacements towards the red is a remarkable feature; it is much greater during this period than in previous years, but taking the whole series of observations since prominence records began at Kodaikanal in 1904 there is found to be a very marked preponderance of shifts towards the red. Up to the end of 1911, 515 displacements have been recorded of which 305 or 59·2 per cent. were towards the red. In recording these displacements it is impossible to distinguish between symmetrical widening of the lines due to increased density of the hydrogen, and symmetrical widening in both directions due to motions in the line of sight, or pressure shifts combined with motion shifts. When the line is bodily shifted from its true position there is little doubt in ascribing it to motion, but in the majority of cases the line is widened on one or both sides, or a sharp wedge-shaped point projects from the line in one or both directions. If all the cases of symmetrical widening were classed separately and deducted from the total number observed, the proportion of displacements towards the red would be increased to 62·4 per cent.

If this tendency towards the red is to be ascribed to motion it appears to involve an effect due to some influence of the earth, and one hesitates to dismiss this as altogether improbable in view of the remarkable preponderance of eastern over western prominences, and the apparent influence of the earth on sunspot phenomena discovered by Mrs. Maunder. On the other hand it is easy to ascribe this tendency to an effect of pressure if we could be sure that pressures of the order required are possible above the photospheric level.

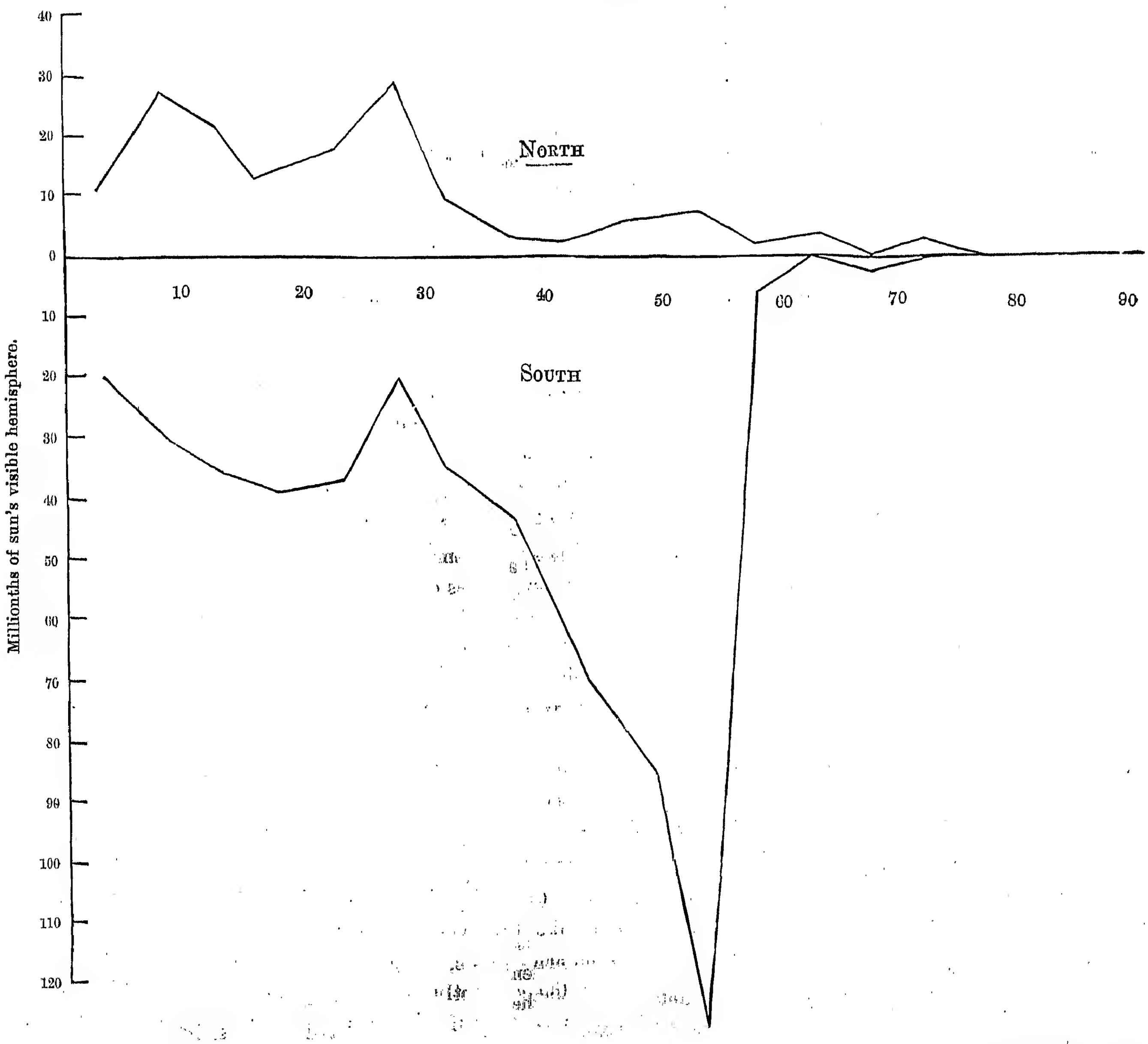
These disturbances show on the whole a very marked preference for the eastern limb although the small number recorded during 1912 predominate on the west limb. Of the 515 displacements observed up to the end of 1911, 298 or 57·9 per cent. were on the east limb, a preponderance of which only a small part may be ascribed to the greater frequency of prominences on that limb. It appears that prominences are not only more numerous on the east limb than on the west but they are decidedly more active on the east limb.

Prominences projected on the disk as absorption markings.

Photographs of the sun's disk in Hα light have been obtained since April 1st, 1911 with the autocollimating grating spectroheliograph. During nine months of 1911 photographs were obtained on 161 days and during the first six months of 1912 on 89 days. The distribution in latitude of the absorption markings which appear in a large proportion of the plates during these two periods is shown in the accompanying diagrams in which the mean areas, corrected for foreshortening, are given for each zone of 5° of latitude.

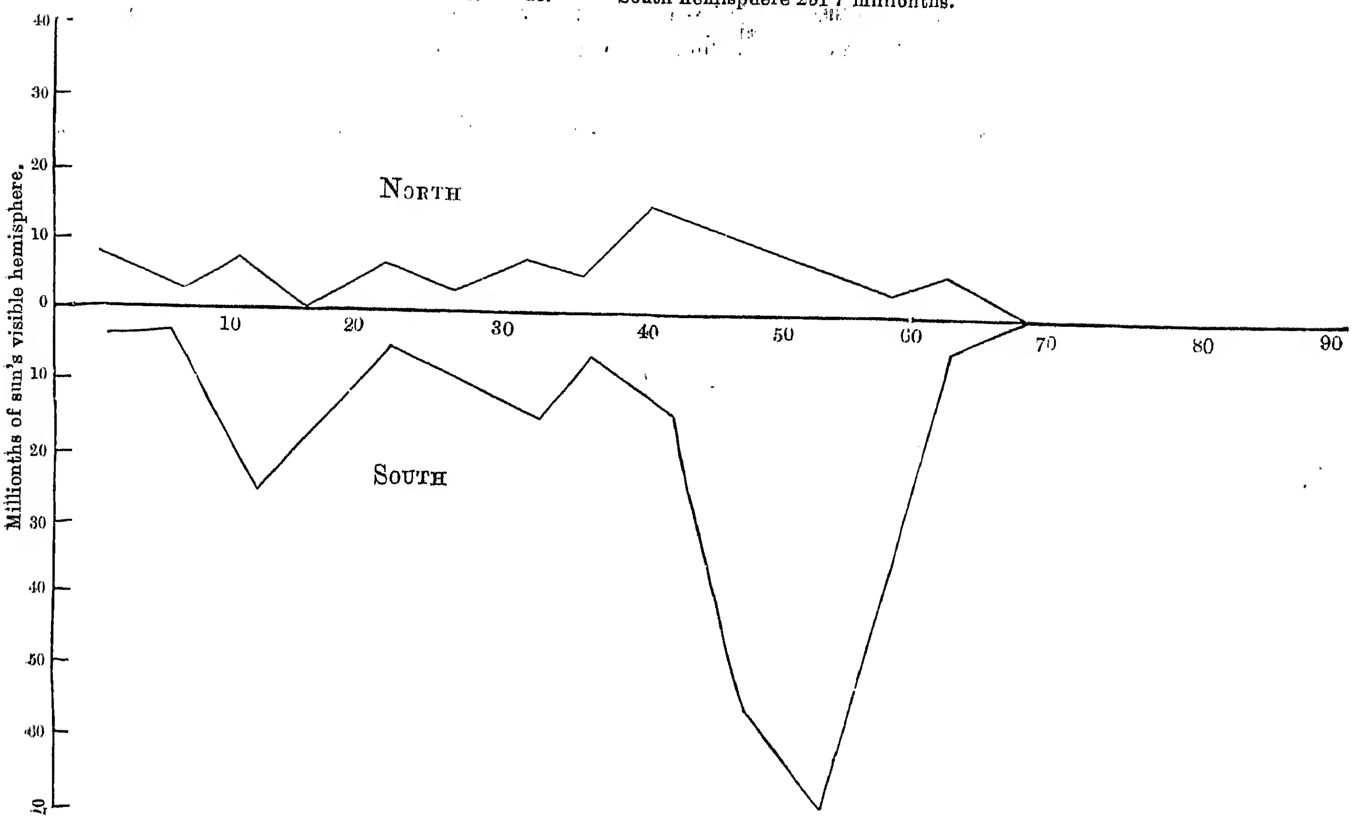
Mean Areas of Hα Absorption Markings.
April 1st to December 31st, 1911.

Total mean area for North hemisphere 162·9 millionths.
Do. do. South hemisphere 706·1 millionths.



MEAN AREAS OF $H\alpha$ ABSORPTION MARKINGS.
JANUARY 1ST TO JUNE 30TH, 1912.

Total mean area for North hemisphere 81·4 millionths.
Do. do. South hemisphere 251·7 millionths.



There is a general similarity of these curves with the prominence distribution curves for the same periods (see page 1, and Kodaikanal Observatory Bulletin No. XXVI, p. 499). The maximum in the southern hemisphere in the zone 45° — 55° and the minimum in the polar regions is the same for prominences and absorption markings, and there is a tendency towards reduced activity at the equator in both. An exact correspondence in the details of the curve is not to be expected on the assumption that the absorption markings are prominences projected on the disk, because, while it seems to be true that every absorption marking is associated with a prominence, only a comparatively small proportion of the prominences indicate their presence on the disk by absorption phenomena.

The high latitude zone of activity between 45° and 55° in the southern hemisphere has produced by far the largest proportion of prominences which show as absorption markings, and these markings tend to form more or less connected chains extending across the disk, a feature which had previously been inferred from the fact that the high latitude prominences at the limb had frequently been observed for many days in succession in nearly the same position angle, and often on both east and west limbs at the same latitude.

The activity in low latitudes, between 5° and 15° north and south in 1911, and between 10° and 15° south in 1912, is closely connected with sunspot disturbances which were prevalent in those regions in both hemispheres in 1911, and in the south only in 1912. A spot disturbance is almost always accompanied by absorption markings, generally of a sharply defined linear character, often curiously sinuous, whilst in the higher latitudes the markings may be described as irregular blotches.

Comparing the two periods under review the general distribution is much the same except that the low latitude activity in the north during 1911 has practically disappeared in 1912. There is a great reduction of mean area in 1912, the totals for the two periods being 869 millionths of the visible hemisphere *per diem* in 1911 and 333 millionths *per diem* in 1912. This reduction is partly connected with the reduction in the number of spots, but the high latitude zones have also shown much smaller mean areas in 1912. The general

reduction is also shown by a comparison of the number of days when no dark markings were found on the plates, this during the first period was 14 per cent. of the whole number and during the second 45 per cent.

Markings on the Hα spectroheliograms which are brighter than the general background have also been frequently photographed. These have invariably been associated with spot disturbances and are the same as have been recorded visually from time to time in the neighbourhood of spots.

KODAIKANAL,
25*th November* 1912.

J. EVERSHED,
Director, Kodaikanal and Madras Observatories.

Kodaikanal Observatory.

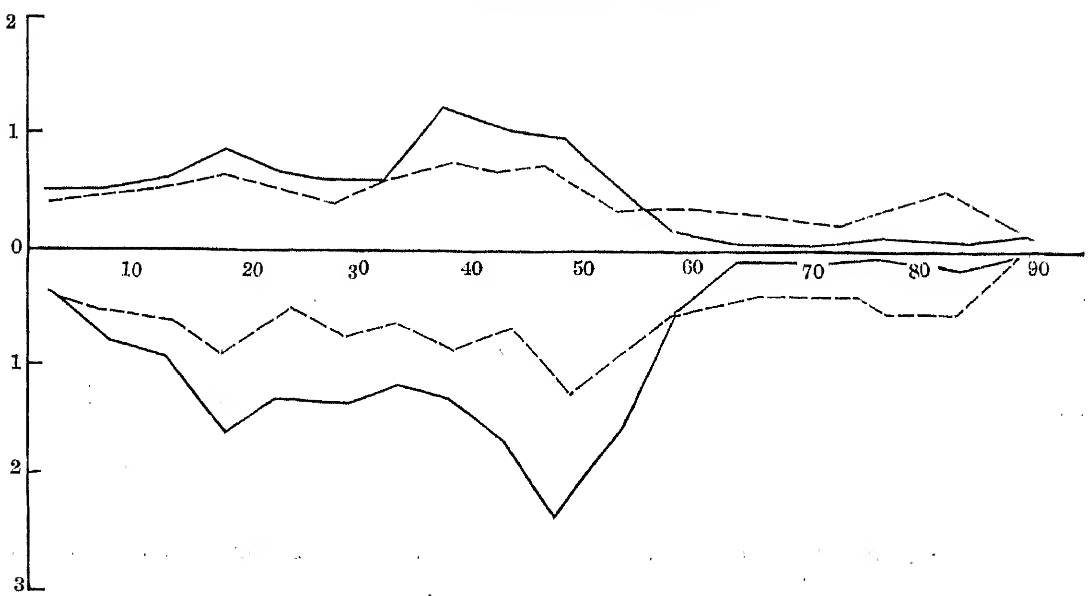
BULLETIN No. XXX.

SUMMARY OF PROMINENCE OBSERVATIONS FOR THE SECOND HALF OF 1912.

The distribution of the prominences in latitude during the six months ending December 31, 1912, is represented in the accompanying diagram. In this the full line gives the mean daily areas and the broken line the mean daily numbers for each zone of 5° of latitude. The scale of ordinates represents tenths of square minutes for the full line and numbers for the broken line. Both are corrected for partial or imperfect observations, the total of 130 days of observation being reduced to 114 " effective " days.

MEAN AREAS AND MEAN NUMBERS OF PROMINENCES—
JULY 1 TO DECEMBER 31, 1912.

Mean areas—full line.
Mean numbers—broken line.



There is a very slight reduction of activity compared with the previous six months, affecting chiefly the numbers for the southern hemisphere. The curves differ but little in form from those of the first half of the year. The polar regions to latitude 60° show the smallest activity, and the equatorial region extending for a few degrees on either side of the equator is also a region of relative poverty in prominence formation. A new zone of activity is indicated between 15° and 20° south but the zone of maximum activity remains as before between the parallels 45° and 50° south latitude. The general preponderance of the southern hemisphere over the northern is still maintained.

The mean daily areas and numbers for each hemisphere corrected for partial observations are as follows:—

	Mean areas (square minutes).	Mean numbers.
North	0·90	8·8
South	1·53	10·5
Total ..	2·43	19·3

The monthly, quarterly, and half-yearly frequencies, corrected for partial observations, are given in the following table in which the mean height and mean extent are also given.

Abstract for the second half of 1912.

Months.	Number of days of observation.		Number of prominences.	Mean daily frequency.	Mean height.	Mean extent.
	Total.	Effective.				
					″	°
July	17	14	224	16·0	25·6	1·27
August	22	19	358	18·8	28·4	1·85
September	27	23	430	18·7	30·3	1·15
October	21	18	258	14·3	32·0	1·30
November	18	16	359	22·4	28·1	1·87
December	25	24	574	23·9	27·6	1·16
Third quarter	66	56	1012	18·1	28·5	1·15
Fourth quarter	64	58	1191	20·5	28·7	1·24
Half-year	130	114	2203	19·3	28·6	1·20

Compared with the previous six months the mean frequency has fallen off by about 4 per cent., but this is compensated by an increase in the mean extent of the prominences, so that the mean area for the whole sun is practically the same for both periods.

Mean height.

The average apparent height of the prominences, 28″·6, is almost identical with that found for the previous six months.

The total number of prominences recorded during the 130 days of observation which attained an apparent height of 60″ or more was 214, which gives a daily average almost equal to that of the first half of the year. The highest prominences recorded were observed on September 30 at latitude — 33° east and on November 12 at latitude — 19° west. Both of these attained a height of 240″.

The larges tprominence recorded during the period was photographed on August 31 between latitude — 15° east and — 35° east. This had the form of a large cloud suspended at a considerable elevation above the chromosphere and connected therewith by very slender arch like filaments at $9^h\ 11^m$. The details of these filaments underneath the main mass were rapidly changing and at $9^h\ 45^m$ had assumed a stippled appearance, being composed for the most part of minute bright points. The under-surface of the cloud was very definitely bounded and brighter than the upper surface, and the cloud ended abruptly at latitude — 35°. At this point the lower surface was 40″ above the photosphere at $8^h\ 11^m$ but rose to 70″ at $9^h\ 11^m$ and 90″ at $9^h\ 45^m$. The top of the highest part of the cloud near its northern end rose from 136″ at $8^h\ 11^m$ to 156″ at $9^h\ 11^m$ and 162″

at $9^h 45^m$. A later photograph taken under cloudy conditions at $10^h 11^m$ showed that no marked increase in height had occurred. The prominence was comparatively short lived as no trace of it was visible on the previous or subsequent days.

Distribution east and west of the sun's axis.

The eastern limb shows a slight preponderance in numbers over the western, whilst for areas the west limb gives the larger totals. The figures are:—

1912 July to December.	East.	West.	Percentage east.
Numbers observed	1115	1091	50·54
Total areas in square minutes of arc	130·4	146·6	47·08

Metallic prominences.

Metallic prominences were exceedingly infrequent only four being observed during the six months, particulars of these are given in the following list:—

Metallic prominences during the second half of 1912.

Date.	Time I.S.T.	Base.	Latitude. North.	Latitude. South.	Limb.	Height.	Elements giving bright lines.
	H. M.	°	°	°			
July 31	8 51	1	78·5	...	West.	20″	Na, Mg and p. Fe.
September 10	9 00	3	...	32	East.	25″	Na, Mg and p. Fe.
November 2	8 48	6	...	18	East.	45″	Na, Mg and p. Fe.
„ 7	8 39	2	35	...	East.	15″	Na, Mg and p. Fe.

Displacements of the hydrogen lines.

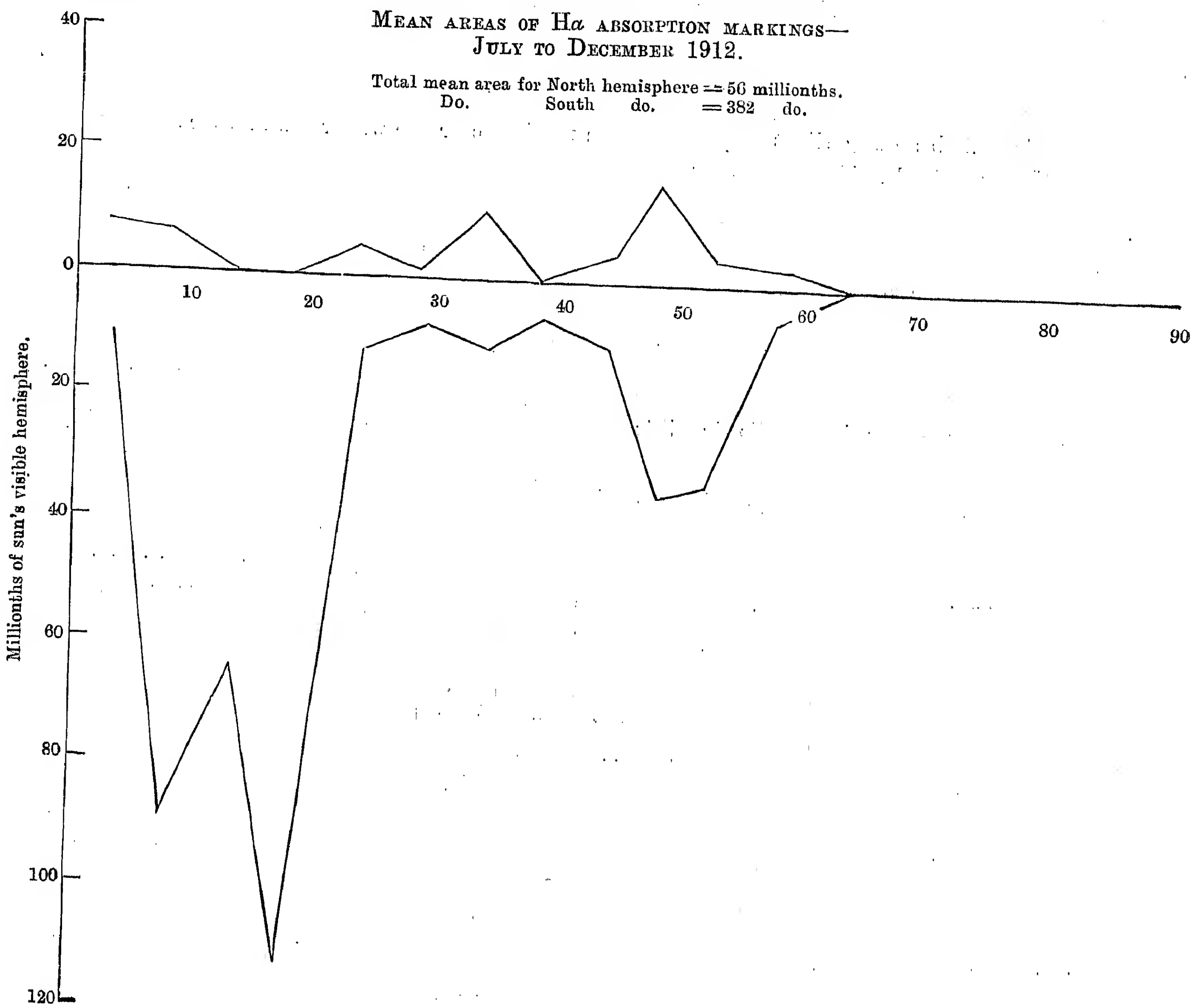
Nineteen displacements of the C line were noted, ten of these were in high latitudes (60° or over), eight in middle latitudes between 20° and 60°, and one in latitude 18°. The greatest displacement observed amounted to 5Å towards the red, this was in the metallic prominence of November 2 at —18° east. It may be noted that all the displacements exceeding 0·5 Å were towards the red and on the east limb, and of the total number observed fourteen were towards the red and six towards the blue, whilst eleven were on the east limb and eight on the west.

The preference for the east limb and the preponderance of displacements towards the red is in accordance with the averages obtained during the past eight years.

Prominences projected on the disc as absorption markings.

The sun's disc was photographed in *Hα* light on 63 days and on 29 of the plates absorption markings are seen. The distribution in latitude of these are given in the accompanying diagram in which the mean areas, corrected for foreshortening, are given for each zone of 5° of latitude. This curve differs markedly from those obtained for the periods 1911 April to December, and 1912 January to June. The greatest development of markings is here found to be in low latitudes in the southern hemisphere between the limits 5° and 20°, whilst there are secondary maxima at —45° to —55° and + 45° to + 50° corresponding with the prominence maxima in those zones. On referring to the prominence curve on page 9 there is seen to be a secondary maximum in the zone — 15° to — 20° which does not occur in the previous periods; the prominences in this

new zone of activity seem to have been accompanied by a larger proportion of absorption markings than those in other regions.



The mean areas in millionths of the sun's visible hemisphere and the mean numbers are compared in the following table with the previous six months :—

	1912 January to June.		1912 July to December.	
	Areas.	Numbers.	Areas.	Numbers.
North	81	0·39	56	0·32
South	252	1·07	382	1·28
Total ..	333	1·46	438	1·60

From this it is seen that there has been a decrease in the northern hemisphere which has been more than compensated by an increase in the south, so that on the whole there has been a considerable increase of area. This is entirely due to the development of markings in the zone — 5° to — 20°.

The distribution east and west of the central meridian of the sun shows a distinct preponderance of east over west, the figures are :—

	Total areas.	Total numbers.
East	1047	58
West	714	42

Only four out of one hundred absorption markings were associated with sunspot disturbances, this is due to the paucity of spots, only three spots appearing on the plates during this period.

THE OBSERVATORY, KODAIKANAL,
27th February 1913.

J. EVERSHED,
Director, Kodaikanal and Madras Observatories.

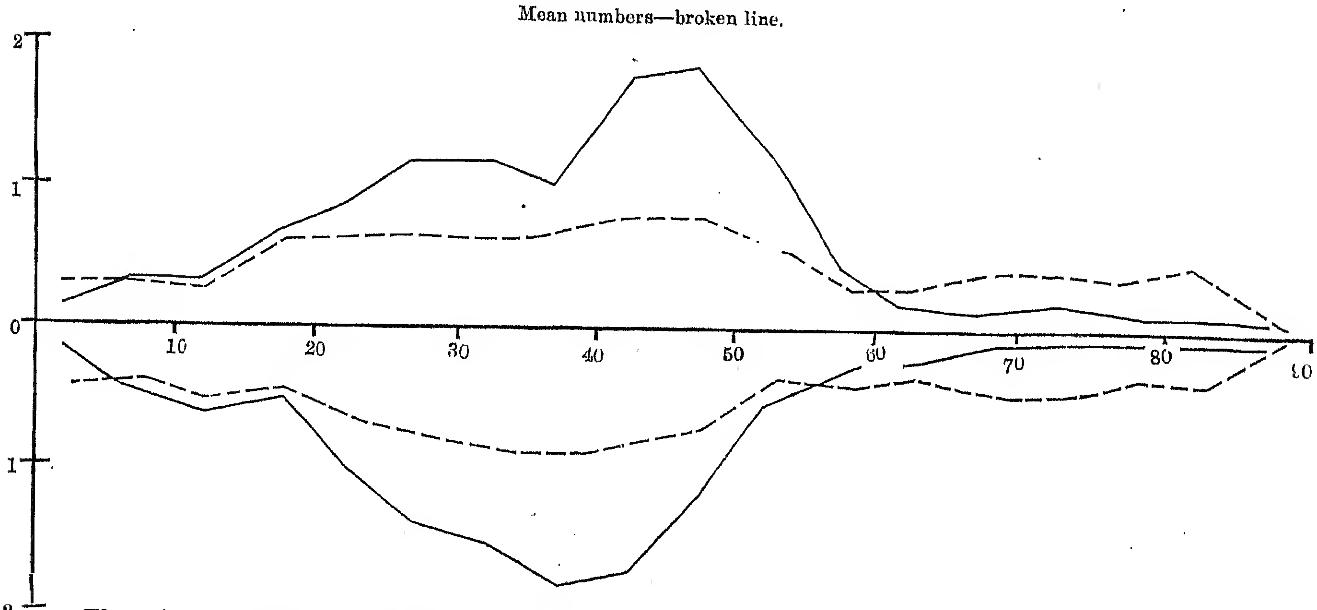
Kodaikanal Observatory.

BULLETIN No. XXXI.

SUMMARY OF PROMINENCE OBSERVATIONS FOR THE FIRST HALF OF THE YEAR 1913.

THE distribution of the prominences in latitude during the six months ending June 30, 1913, is represented in the accompanying diagram. In this the full line gives the mean daily areas, and the broken line the mean daily numbers, for each zone of 5° of latitude. The scale of ordinates represents tenths of square minutes of arc for the full line and numbers for the broken line. The means are corrected for partial or imperfect observations the total of 166 days of observation being reduced to 153 "effective" days

MEAN AREAS AND MEAN NUMBERS OF PROMINENCES.
JANUARY 1ST TO JUNE 30TH, 1913.
Mean areas—full line.
Mean numbers—broken line.



There is a reduction of area in the southern hemisphere compared with the previous six months and an increase in the north, the area for the whole sun remaining the same. The reduction in the south affects chiefly the zones 15°—20° and 45°—50° and the increase in the north is mainly in the region 40°—50°.

By these changes the two hemispheres have become sensibly equal in activity both as regards areas and numbers.

The usual reduction of area is shown in the polar regions (60° to 90°) and in the immediate vicinity of the equator, indicating the general dependence of the distribution on the solar rotation.

The mean daily areas and numbers for each hemisphere corrected for partial observations are as follows :—

	Mean areas (Square minutes.)	Mean numbers.
North	1·23	9·61
South	1·19	9·56
Totals ...	2·42	19·17

The monthly, quarterly, and half yearly frequencies, corrected for partial observations, and the mean height and extent, are given in the following table:—

Abstract for the first half of 1913.

Months.	Number of days of observation. Total.	Number of days of observation. Effective.	Number of prominences.	Mean daily frequency.	Mean height.	Mean extent.
					″	°
January	26	23	461	20·0	29·9	1·39
February	27	25	515	20·6	29·9	1·15
March	31	30	653	21·8	29·2	1·14
April	29	28	530	18·9	30·3	0·99
May	28	26	448	17·2	30·0	1·03
June	25	21	327	15·6	26·3	0·86
First quarter	84	78	1629	20·9	29·3	1·21
Second quarter	82	75	1305	17·4	29·2	0·97
Half year	166	153	2934	19·2	29·2	1·11

Compared with the previous six months the mean frequency has remained practically unaltered, the mean height has slightly increased and the mean extent has slightly diminished.

Mean height.

The mean apparent height of the prominences, 29″·2, exceeds that found for the previous six months by 0″·6.

The total number of prominences recorded during 166 days of observation which attained heights of 60″ or more is 334 or an average of 2·0 per diem as against 1·6 per diem during the latter half of 1912. Five prominences were photographed exceeding 180″ in height. The highest was photographed on January 26th at latitude +30° west. This was a small pointed cloud closely resembling in form the brighter part of the nebula photographed near Nova Persei. At 8^h 20^m it was about 4′ above the sun's limb but appeared to be receding from the sun at a speed of about 30 kilometers per second, and at 9^h 50^m it was outside the field of the spectroheliograph.

Distribution east and west of the sun's axis.

The eastern limb shows a slight preponderence in numbers and areas over the western as follows:—

1913 January to June—

	East.	*West.*	Percentage east.
Numbers observed	1485	1449	50·61
Total areas in square minutes of arc ...	187·4	182·2	50·70

Metallic prominences.

Only five were observed during the six months, particulars of these are given in the following table:—

Metallic prominences during the first half of 1913.

Date.	Time I.S.T.	Base.	Latitude. North.	Latitude. South.	Limb.	Height.	Elements giving bright lines.
	H. M.	°	°	°		″	
January ... 4	8 44	1	25·5	...	E	40	Na, Mg, *p*Fe.
Do. ... 4	8 55	...	26	...	W	10	Na, Mg, *p*Fe.
March 13	8 35	1	...	46·5	W	25	Na, Mg, *p*Fe.
Do. 26	8 24	2	...	44·5	W	70	Na, Mg, *p*Fe and He.
Do. 26	8 24	0·5	...	41·5	W	25	Na, Mg, *p*Fe and He.

It is remarkable that two were observed on the same day (January 4) and at the same latitude, one being on the north-east limb and the other on the north-west limb; the latter was an exceedingly bright point of light exactly over a small sunspot (Greenwich No. 7008, Latitude + 26°).

Displacements of the hydrogen lines.

The number of displacements observed has largely increased compared with the record for the previous six months. This is partly due to increased attention being given by the observers to these observations and partly to the use of more powerful instruments during the last three months. Altogether 87 of these disturbances were recorded and more than half the number (49) were in the high latitude areas between 60° and the poles. Twenty-three were in mid-latitudes 30° to 60°, and fifteen in the equatorial region bounded by latitude 30°.

The largest displacement recorded was on February 1st at latitude + 81° east when the C line was displaced 3 Å towards the red at $9^h\ 40^m$. Two minutes later it had changed to 3 Å towards the violet and at $9^h\ 51^m$ the disturbance had subsided.

Forty-five of the displacements were towards the red, thirty-two towards the violet and ten in both directions simultaneously. Fifty-six were on the east limb and thirty-one on the west. Finally the disturbances were almost equally distributed north and south of the equator.

Reversals and displacements of the hydrogen lines on the disc.

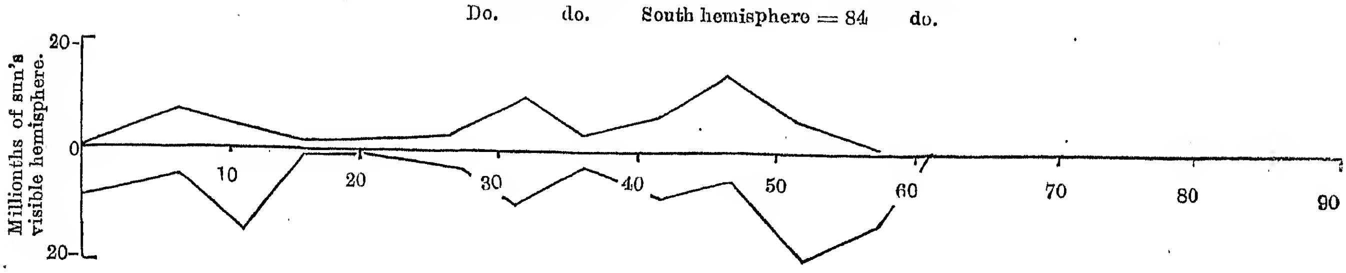
These disturbances being closely associated with sunspots are rarely observed during years of minimum spot activity. No noticeable disturbances of the C line were recorded near the small spots of January, March and April but on February 21st $8^h\ 20^m$ the dark line was displaced about 3Å towards the red near spot No. 7010 of the Greenwich series (Latitude + 27°) and on the 22nd $10^h\ 18^m$ the line was reversed in several places between main spot and the group of small spots following.

Prominences projected on the disc as absorption markings.

The sun's disc was photographed in Hα light on 132 days and on 57 of these days absorption markings are shown. The distribution of the markings in latitude are given in the accompanying diagram in which the mean areas, corrected for foreshortening, are given for each zone of 5° of latitude.

MEAN AREAS OF Hα ABSORPTION MARKINGS.
JANUARY TO JUNE 1913.

Total mean area for North hemisphere = 44 millionths.
Do. do. South hemisphere = 84 do.



The general distribution is almost the same as that of the prominences at the limb, the only noticeable difference is in the southern hemisphere where the maximum development of absorption markings is in a higher latitude than the maximum area of prominences. In the northern hemisphere the correspondence of the two curves is very close. As the majority of prominences do not produce absorption on the disc the diagram represents a much smaller number of observations than is the case with the prominence diagram on page 13.

Compared with the previous six months (See Kodaikanal Observatory Bulletin No. XXX, page 12) it appears that the three principal zones of activity in each hemisphere are in exactly the same latitudes in both periods, but the very active zone observed in 1912 at 10° to 20° south has in 1913 become of secondary importance. The reduction of activity in this zone is also shown in the prominence curves.

The mean areas per diem in millionths of the sun's visible hemisphere and the mean numbers are compared in the following table with the previous six months :—

	1912 July to December.		1913 January to June.	
	Areas.	Numbers.	Areas.	Numbers.
North ...	56	0·32	44	0·24
South ...	382	1·28	84	0·56
Total ...	438	1·60	128	0·80

There is here shown a great reduction in both numbers and areas in 1913, the mean numbers being reduced by half and the mean areas $3\frac{1}{2}$ times, so that the average size of the markings has also greatly decreased.

THE OBSERVATORY, KODAIKANAL,
14th July 1913.

J. EVERSHED,
Director, Kodaikanal and Madras Observatories.

Kodaikanal Observatory.

BULLETIN No. XXXII.

A NEW METHOD OF MEASURING SMALL DISPLACEMENTS OF SPECTRUM LINES.

In the course of measurement of many series of spectra photographed with the Kodaikanal grating spectrograph a new method of measuring suggested itself which seemed to give promise of appreciably reducing the accidental and systematic errors inherent in the ordinary method of bisecting a spectrum line with a straight spider thread.

The essence of the new method consists in placing a positive copy of the plate to be measured reversed, and almost in contact with the negative, film to film, and moving one with reference to the other so that the positive images are made to coincide successively with the negative images of the corresponding lines.

No spider thread is used, and the accuracy of the adjustment for coincidence depends on the sensitiveness of the eye in estimating the change from the bright and dark contiguous images of a line, to the perfectly uniform density which results when the positive image exactly coincides with the negative, and the positive copy has the same gradation of tone as the negative.

The delicacy of this adjustment is greater than might have been anticipated, and it is independent of the width of the lines. The displacement of the D lines for instance at the sun's limb due to the solar rotation can be measured almost, if not quite, as accurately as that of the much narrower lines of Fe etc. Experience has shown that given the same amount of training in the new method as in the old, the adjustment for coincidence of a positive and negative image of a solar line can be made with almost the same apparent accuracy as in bisecting the line with a thread. A good deal of course depends on the contrast in the original negative, and in the case of the sharply defined and very dense emission lines of the arc or spark spectrum the adjustment for coincidence can be made with greater accuracy than is possible in setting a thread central on the line.

The principal advantage claimed for the new method is in the reduction of the accidental errors by reason of the double intervals measured. It is in fact almost equivalent to doubling the linear dispersion of a plate without altering the width or definition of the lines. The method appears also to be entirely free from the large systematic bias which most observers become aware of when estimating displacements between the lines in an absorption spectrum and in a comparison spectrum of bright lines.

The detection of asymmetry in a spectrum line is of interest and importance in some researches. By the method of reversing a positive end for end on a negative the slightest want of symmetry is revealed, since the less refrangible edge of a line in the copy is superposed on the more refrangible edge of the negative and the condition of perfect uniformity of density when the centres coincide is destroyed if the edges of the line are not similar. This reversal end for end is not essential for the measurement of displacements and where the lines in a spectrum are thickly crowded, as in the violet and ultra violet solar spectrum, it is better to take the positive copy through the glass. It is then not necessary to reverse it end for end on the negative.

The new method is applicable where the spectrum to be measured does not exceed 2–3 mm. in width with a comparison spectrum contiguous to it on one or both sides. It has been used successfully to measure the displacements between sun and arc spectra where the arc lines are impressed on both sides of the solar spectrum, and to solar spectra where the central strip represents the sun's limb and the side spectra represent the centre of the disc; also to solar rotation plates where east limb and west limb spectra form two contiguous strips, or east limb, centre of disc and west limb spectra form three contiguous strips.

Where the side spectra are the same as in the first two cases mentioned a positive copy may be taken in the ordinary way and reversed end for end on the negative and the lines brought successively into coincidence.

If there are only two contiguous spectra, or three dissimilar spectra, it is necessary to obtain a *reversed* positive to place on the negative. This may be done in several ways. A positive may be printed through the glass with parallel light, or without using a collimating lens, by exposing for a few seconds to a naked electric arc placed at a distance of not less than 50 feet, and screening the plate from scattered light. Another method is to take two contact copies in the ordinary way developing one as a positive, and reversing the other to a negative with ammonium persulphate or other bleaching agent. The negative so obtained can be used on the positive. A third method which I have found to be much the most satisfactory is to take a single copy of the original negative with a long focus photographic lens using a moderately fast plate and placing the negative with the glass side towards the lens. If the conjugate foci are made equal the positive can be used on the negative.

In many cases it is an advantage to enlarge the original about one and a half or two-fold. In this case the procedure is as follows: an ordinary contact positive is made on a moderately fast plate and developed so that it has the same gradation of tone as the negative. The positive and the original negative are then copied with the enlarging camera, using lantern plates to increase the contrast. In copying, the positive must be placed with the film side towards the lens, and the negative with the glass side towards the lens (or *vice versa*) care being taken to place the film in each case at precisely the same distance from the lens so that the scale of the two copies is the same. Very satisfactory results have been obtained by this method, the enlargement and increase of contrast being a distinct gain in measuring.

By the ordinary method of measuring I have found no advantage in enlarging a plate if the scale of the original is not less than one millimetre to the angstrom because the increased width of the spectrum lines in the copy and the more obtrusive irregularities of grain militate against the accurate bisection of a line with the spider thread. With the new method neither the width of the lines nor the grain of the plate has very much effect on the accuracy of setting. With the spectrograph I have employed the scale of the original negatives is made as large as is consistent with reasonable exposure times. With a Rowland $3\frac{1}{4}$-inch grating of 15,028 lines to the inch the scale ranges between 1·2 mm and 2·0 mm to the angstrom and these may be enlarged with advantage up to 3 or 4 mm. to the angstrom.

The photographically reversed positive may be placed on the negative film to film and either reversed end for end or not reversed. If the relative displacements between three different spectra are to be measured it must be so reversed, but for two spectra only it may be either way. When not reversed end for end the positive and negative images of all the lines on one spectrum come into coincidence simultaneously, and the entire spectrum assumes a uniform grey tint devoid of all details. In this way it is possible to obtain a generalized measurement of the displacements of all the lines of the two spectra by measuring the amount of movement required between the two plates in order to obtain this uniform tint, first in one spectrum and then in the other, half of this movement being equal to the mean displacement of the lines. A fairly accurate estimate of the mean result of a plate can in this way be made very rapidly.

In addition to the advantages already mentioned the following may also be claimed for the new method.

In measuring displacements of two contiguous spectra by the ordinary method a troublesome correction has to be applied for the inclination of the thread to the spectrum lines, this being determined by numerous subsidiary measures. This correction is entirely avoided by the new method if the spectrum lines may be assumed normal to the spectrum, for it is easy to adjust the positive and negative plates with the spectra

exactly parallel to one another lengthwise so that the lines will also be parallel. With a properly designed slit the spectrograph may be accurately adjusted once for all to give spectra in which the lines are exactly normal to the spectrum.

In measuring with the photographically reversed positive so that the positive may be placed on the negative without reversing end for end, unsymmetrical lines may be measured with the same accuracy as symmetrical lines, which is far from being the case in bisecting with a thread; also with closely clustered lines such as occur in the violet and ultra violet part of the solar spectrum the measures can be made by groups instead of single lines, for all the lines of one spectrum disappear simultaneously when the positive and the negative are brought into coincidence. This group method eliminates accidental irregularities in the distribution of the silver grains which certainly affect the measures of individual lines to some extent by any method of measuring.

Finally the strain on the eyes seems to be less severe in estimating densities of line images of considerable width compared with the strain of concentrating attention on an exceedingly narrow thread and trying to place it central on a less well defined line image.

The following fairly obvious objections may be made to the method:—

(1) The extra time and trouble required in making suitable positives and in setting up the plates for measurement.

(2) The possibility of new sources of error introduced in copying especially when copies are obtained through the glass.

(3) Errors due to a parallax effect caused by the distance separating the two films.

(4) Confusion resulting from the multiplication of images in the field of view of the microscope.

Objection (1) must be weighed against the increase of accuracy obtained. The extra trouble in setting up the plates for measurement may be largely mitigated by suitably designed apparatus.

With regard to (2) the experience of the writer is that no measurable distortion occurs in the lines of a spectrum in copying either by contact, or with a lens and through the glass. If such distortion does occasionally occur such errors may be treated as purely accidental.

(3) Errors due to a parallax effect become appreciable if the positive and negative plates are separated by intervals greater than ·5 mm.; with suitable apparatus however the plates can be brought to within 0·05 mm. if the upper plate is cut as small as possible.

(4) The confusion of images is sometimes rather baffling when the positive is reversed end for end on the negative. With experience in working the method this difficulty disappears.

Apparatus.

The accompanying drawing shows the essential features of the apparatus that has been used. A photograph of the micrometer with the apparatus attached is also given.

In the drawing P is a sliding brass plate 12 inches long × $2\frac{1}{2}$ inches wide and having an opening or slot cut along the centre lengthwise about $\frac{1}{2}$ inch wide and 6 inches long. Two strips of wood are screwed to the plate underneath, one on each side of the opening; these form the mounting to which the positive is gummed film downwards.

Above P is a flat piece of hard wood W, $\frac{1}{4}$ inch thick, 7 inches long, and the same width as P. This also has an opening cut in the centre. Brass angle pieces A_1 A_2 are screwed to the wood along the edges; these support and guide the sliding plate. The edges of P are ground straight and parallel, and the inner surfaces of A_1 are filed true. Between the angle piece A_2 and the edge of the sliding plate a long spring S, made of hard brass wire is inserted; this holds the plate against A_1 and makes the sliding movement smooth and easy. The outer edge of W, and consequently the inner surface of A_1, is made parallel to the ways of the micrometer. The positive being attached to the sliding parts can by this means be moved over the negative, which is fixed to the micrometer stage below, until the corresponding lines are near together; and this movement cannot disturb the adjustment for parallelism of the spectrum lines in the two photographs.

The wood W is attached to the moving carriage of the micrometer by two strong angle pieces made of $\frac{1}{8}$ inch steel plate. One of these R is shown in the drawing. Each is connected to the wood by a screw

passing through a hole in the steel made just large enough to allow the threads to pass freely through. A large nut with milled head *N* fits on each screw, and between the steel and the wood pieces of stout clock spring *C* are placed. By turning the nuts the springs are either compressed or released and the parts below are drawn up or forced down. The positive plate can in this way be raised or lowered and its inclination adjusted to parallelism lengthwise with the negative.

On each of the steel angle pieces there is also provided a screw with milled head *T*. This is screwed through the steel in the position shown, the end bearing on the clock spring; its function is to adjust the inclination of the positive laterally and bring it into parallelism with the negative.

By means of the two adjustments the surfaces of positive and negative are made parallel and brought as near together as the unevenness of the plates will allow, usually within $\frac{1}{20}$ mm. Two clamping screws, *M*, hold the entire apparatus to the sliding carriage of the micrometer. The holes in the vertical part of the steel connecting plates are slotted and by loosening *M* the whole may be raised or lowered through about 10 mm.

The microscope tube is shown in the upper part of the diagram its objective being at *O*, about 3 inches above the plates to be measured. The microscope has a magnifying power of 12 diameters and a large field of view so that a length of 12 mm. of spectrum may be seen.

Method of working.—The negative to be measured is securely fastened to the micrometer stage along its edges by two or more strong dog clips. The sliding plate *P* is withdrawn and the positive copy which is cut as narrow as possible is fastened to the wooden strips with photographic paste. A very suitable adhesive is Higgins vegetable glue as this is not too strong, and when completely dry the plate may be easily detached. Before the gum has set the spectrum is made central and parallel to the edges of the sliding plate. A few minutes are allowed for the gum to set, and before the plate with the positive attached is replaced in the slide the latter is raised to its highest point by loosening the clamps *M*. The plate is then put in and the whole lowered until the positive rests on the negative, film to film; the clamps are then tightened and the nuts *N* are turned so as to raise the positive just clear of the negative, the screws *T* are also slightly turned to adjust the two surfaces parallel. In order to bring the positive and negative spectra into coincidence and parallel to one another lengthwise the negative is adjusted laterally. In the micrometer which has been used for this work the stage is provided with lateral movements which are a great convenience in making this last adjustment.

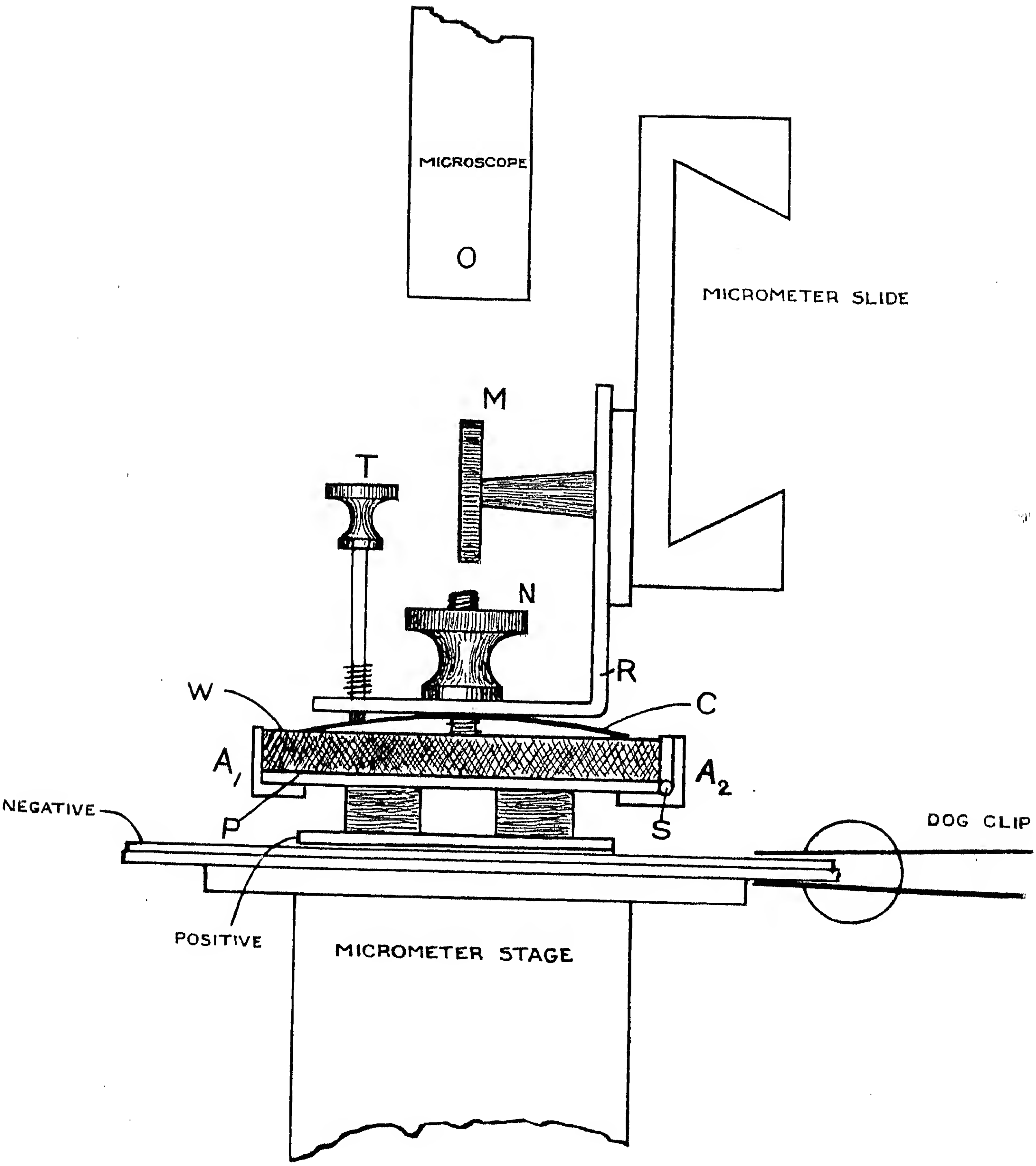
The positive may now be moved by hand over the negative until the corresponding lines in the two plates are near together in the field of view, it is then moved by the micrometer screw to get the successive coincidences of positive and negative images in the two spectra to be compared, the successive readings of the screw giving twice the interval separating the lines.

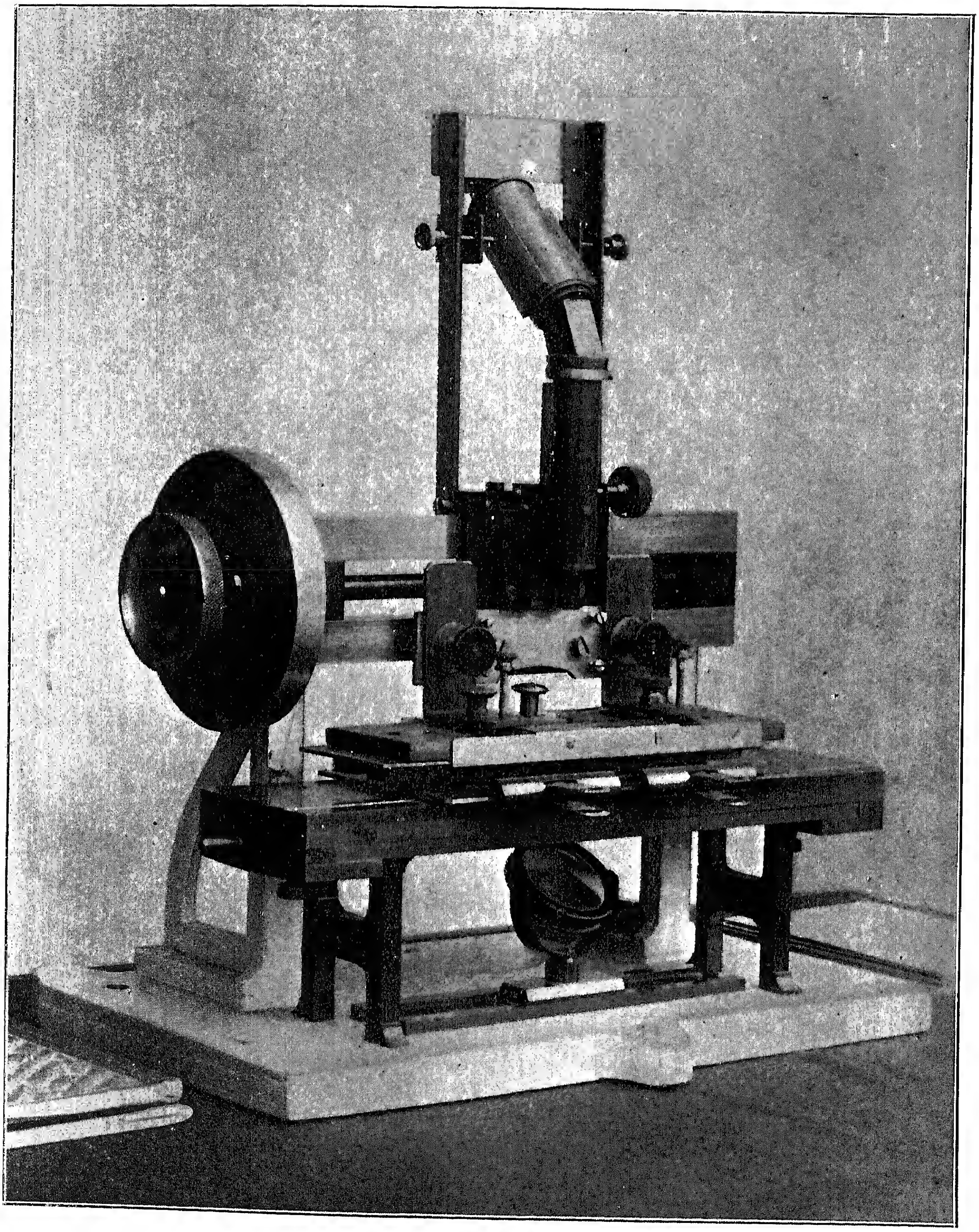
Results.

I give below two examples of measures made in the ordinary way and by the new method, to show the relative accuracy obtained. These represent two series of solar rotation plates. In the first series (example I) the exposures were made alternately on the sun's east and west limbs, the central strip of spectrum representing the west limb and the two side strips the east limb. An ordinary positive reversed end for end on the negative was used in the new method of measuring, the original negative being used for the ordinary measures. In the second series (example II) the exposures were made simultaneously on east and west limbs, these being represented by two contiguous strips of spectrum each 3 mm. in width. The original negative was used for the ordinary method of measuring, and copies enlarged 1·4 times for the positive on negative method.

I.—SOLAR ROTATION PLATE.

Date—February 28, 1911.		Alternate exposures—
Latitude (mean)	$1^\circ{\cdot}4$	centre strip west limb $\phi = 2^\circ{\cdot}1$.
Angle D	$7^\circ{\cdot}2$	side strips east limb $\phi = 0^\circ{\cdot}8$.
Correction to limb	$\frac{1}{80}$	


MICROSCOPE
O
MICROMETER SLIDE
M
T
N
R
W
C
A_1
A_2
NEGATIVE
P
S
DOG CLIP
POSITIVE
MICROMETER STAGE



Ordinary method.

λ		Direct.	Reversed.	Mean.	Factors.	$\frac{\Delta\lambda}{2}$	Km/sec.	Residuals.
		mm.	mm.	mm.		Å		
6252·773	...	·133	·128	·131	·5553	·0363	1·74	− 1
6256·572	...	·137	·138	·137	·5532	·0379	1·82	+ 7
6261·316	...	·137	·123	·130	·5505	·0358	1·72	− 3
6265·348	...	·139	·137	·138	·5481	·0379	1·81	+ 6
6270·442	...	·124	·135	·130	·5454	·0354	1·69	− 6
6280·833	...	·144	·135	·140	·5395	·0378	1·80	+ 5
6291·184	...	·147	·137	·142	·5339	·0379	1·80	+ 5
6298·007	...	·137	·139	·138	·5301	·0367	1·75	0
6301·718	...	·136	·136	·136	·5281	·0359	1·71	− 4
6302·709	...	32	·131	·132	·5276	·0347	1·65	−10

Mean ... ... 1·749
Probable error ... ... ± ·012

Positive on negative method.

λ		Direct.	Reversed.	Half mean.	Factors.	$\frac{\Delta\lambda}{2}$	Km/sec.	Residuals.
		mm.	mm.	mm.		Å		
6252·773	...	·263	·251	·129	·5553	·0357	1·71	+ 1
6256·572	...	·261	·251	·128	·5532	·0354	1·70	0
6261·316	...	·258	·253	·128	·5505	·0352	1·69	− 1
6265·348	...	·253	·255	·127	·5481	·0348	1·66	− 4
6270·442	...	·248	·260	·127	·5454	·0346	1·66	− 4
6280·833	...	·263	·265	·132	·5395	·0356	1·70	0
6291·184	...	·272	·279	·138	·5339	·0368	1·75	+ 5
6298·007	...	·276	·270	·136	·5301	·0361	1·72	+ 2
6301·718	...	·267	·265	·133	·5281	·0352	1·68	− 2
6302·709	...	·272	·271	·136	·5276	·0358	1·71	+ 1

Mean ... ... 1·697
Probable error ... ... ± ·006

	Km/sec.
Mean result of plate giving equal weights	1·724
Correction to limb	+ ·057
Correction for secant of angle D	+ ·014
Correction to equator	+ ·001
Correction for earth's revolution	+ ·141
Sidereal velocity at equator ...	1·937

II.—SOLAR ROTATION PLATE.

Date—May 22, 1913.
Latitude ... ... 8°·5
Angle D ... ... 1°·8
Correction to limb ... ... $\frac{1}{38}$

Simultaneous exposures. East and west strips contiguous.

Ordinary method.

λ	Direct.	Reversed.	Corrected mean.*	Factors.	$\frac{\Delta\lambda}{2}$	Km/sec.	Residuals.
	mm.	mm.	mm.		Å		
5560·434 ...	·115	·124	·117	·5840	·0340	1·84	+ 6
5562·933 ...	·121	·130	·123	·5828	·0358	1·93	+ 15
5565·931 ...	·124	·126	·123	·5818	·0356	1·92	+ 14
5567·621 ...	·110	·112	·108	·5805	·0314	1·69	− 9
5569·848 ...	·118	·118	·115	·5793	·0334	1·80	+ 2
5573·075 ...	·120	·116	·115	·5778	·0333	1·79	+ 1
5576·320 ...	·116	·129	·120	·5762	·0346	1·86	+ 8
5578·946 ...	·115	·124	·117	·5750	·0336	1·81	+ 3
5582·198 ...	·112	·122	·114	·5733	·0328	1·76	− 2
5586·991 ...	·108	·114	·109	·5712	·0309	1·66	− 12
5588·985 ...	·121	·116	·116	·5702	·0331	1·78	0
5590·343 ...	·116	·112	·111	·5695	·0317	1·70	− 8
5601·505 ...	·120	·119	·117	·5640	·0330	1·76	− 2
5615·877 ...	·119	·118	·116	·5571	·0308	1·64	− 14

Mean ... ... 1·782
Probable error ... ... ± ·016

* Correction for inclination of wire − ·0026 mm.

Positive on negative method (enlarged copies).

λ	Direct.	Reversed.	Half mean.	Factors.	$\frac{\Delta\lambda}{2}$	Km/sec.	Residuals.
	mm.	mm.	mm.		Å		
5560·434 ...	·321	·315	·159	4172	·0332	1·79	+ 1
5562·933 ...	·326	·330	·164	·4162	·0341	1·84	+ 6
5565·931 ..	·313	·330	·161	·4152	·0334	1·80	+ 2
5567·621 ...	322	·315	·159	·4146	·0330	1·78	0
5569·848 ...	·325	·323	·162	·4138	·0335	1·80	+ 2
5573·075 ...	·316	·327	·161	·4127	·0332	1·79	+ 1
5576·320 ...	·332	·319	·163	·4116	·0335	1·80	+ 2
5578·946 ...	·332	·299	·158	·4107	·0324	1·74	− 4
5582·198 ...	·340	·315	·164	·4095	·0335	1·80	+ 2
5586·991 ...	·322	·307	·157	·4078	·0320	1·72	− 6
5588·985 ..	·324	·320	·162	·4072	·0329	1·77	− 1
5590·343 ...	·315	·314	·157	·4067	·0320	1·71	− 7
5601·505 ...	·335	·330	·166	·4027	·0334	1·79	+ 1
5615·877 ...	·331	·337	·167	·3977	·0332	1·78	0

Mean ... ... 1·779
Probable error ... ... ± ·006

	Km/sec.
Mean result of plate giving equal weights	1·780
Correction to limb	+ ·047
Correction for secant of angle D	+ ·0002
Correction to equator	+ ·034
Correction for earth's revolution	+ ·135
Sidereal equatorial velocity ...	1·996

The measures were made by myself and the same amount of care and attention was given to each method. The plates were first measured with the red end to the right hand and then reversed and the measures repeated. The results in fractions of a millimetre are given in the second and third column, and the means in the fourth column; halved in the case of the new method which measures the double interval. The column headed $\frac{\Delta\lambda}{2}$ gives the half interval in angstroms and this is converted into kilometres per second in the last column but one.

It is seen that the residuals are notably smaller in the case of the positive on negative measures, and the resulting probable error is half that derived from the ordinary measures in I, and less than half in II. Up to the present fourteen rotation plates have been measured by both methods and in all of these the residuals are smaller by the new method, the average probable error being ± ·015 km/sec. by the old method and ± ·009 km/sec by the new. This is a somewhat smaller difference between the methods than is shown above, but some of the earlier measures show larger probable errors which are doubtless due to inexperience in working the new method.

It will be noticed that in the first comparison there is a systematic difference amounting to nearly 3 per cent. in the mean results of the two methods. This is not easily explained, the inclination of the thread in the ordinary measures is in this case automatically allowed for in taking the mean readings of the two side spectra which are similar; and there appears to be no other source of systematic error. I can only suggest that personal bias affects one or other method, and I think it probable that the smaller values are the more correct. It is possible that in measuring in the ordinary way there is a tendency to exaggerate displacements even when, as in my own measures, a sliding mask is used to limit the field of view to one spectrum at a time. In all the rotation spectra I have measured in duplicate the old method gives larger values of the displacement than the new but there is often some uncertainty as to the correction for inclination of the thread. The average value of the sidereal velocity at the sun's equator from 14 plates is 1·946 km/sec. for the old method and 1·925 km/sec. for the new.

In example II the agreement of the mean results is very close but this is possibly accidental. The correction for inclination of the wire is determined by measuring the lines of the arc spectrum of iron impressed on the plates outside the solar spectra and in this plate only four arc lines are strong enough for measurement. The results given by these lines were not very consistent and the correction is therefore somewhat uncertain.

In measuring by either method the mean of five settings is taken as the reading for each line, and from the accordance of the individual settings the probable errors of the readings have been computed for all the lines in the two plates. The probable errors of the difference of readings, *i.e.*, the displacements were then derived for each line. The average probable error of a line derived in this way does not differ materially from that derived from the accordance of the different lines, as is shown below:—

Probable errors of a single line.

		By accordance of lines.	By accordance of settings.
No. 1	Ordinary method	± ·039 Km/sec.	± ·049 Km/sec.
,,	Positive on negative	± ·019 ,,	± ·030 ,,
No. 2	Ordinary method	± ·050 ,,	± ·060 ,,
,,	Positive on negative	± ·028 ,,	± ·023 ,,

The number of lines measured being 10 for No. 1 and 14 for No. 2 the probable errors of the mean results of the plates are—

Probable errors of mean results of plates.

	By accordance of lines.	By accordance of settings.
No. 1 Ordinary method	± ·012 Km./sec.	± ·015 Km/sec.
„ „ Positive on negative	± ·006 „	± ·009 „
No. 2 Ordinary method	± ·016 „	± ·013 „
„ „ Positive on negative	± ·006 „	± ·007 „

For these plates therefore the probable error is about halved in the positive on negative measures as compared with the ordinary measures, and the gain in accuracy is about the same whichever way the probable errors are estimated.

The method has been found particularly useful in measuring the small displacements between the lines of the arc spectrum of iron and solar lines at the centre of the disc. In this case also enlargement of the original negative is advantageous. I give as an example a recently measured plate containing five iron lines. The positive and negative plates were enlarged from the original to a scale of 2·7 millimetres to the angstrom.

Date—March 26, 1912. Centre of sun's disc and Fe arc.

Hour angle of sun	24° 45′ east.	
Correction for orbital velocity of earth	+·485	Km/sec.
Correction for diurnal velocity of earth	−·191	„
Total correction = V = ...	+·294	„

λ	Direct.	Reversed.	Mean.	Factors.	$\frac{\Delta\lambda}{2}$	Correction for V.	⊙ — arc.
	mm.	mm.	mm.		Å	Å	Å
4442·510	·069	·073	·071	·3720	·0132	— ·00436	+ ·0088
4447·892	·103	·101	·102	·3711	·0189	— ·00436	+ ·0145
4461·818	·053	·067	·060	·3687	·0111	— ·00437	+ ·0067
4466·727	·075	·079	·077	·3678	·0142	— ·00438	+ ·0098
4494·738	·060	·061	·061	·3639	·0110	— ·00441	+ ·0066

The different lines in this case show very different displacements, as is seen in the last column ⊙ — arc, it is not possible therefore to derive probable errors from the accordance of these as the differences are real. The average probable error for each displacement derived from the accordance of settings is ± ·0003 Å the greatest being ± ·0005 Å and the least ± ·0001 Å. The same mean result is got by a comparison of direct and reversed measures, taking account of the fact that the figures given in the 2nd, 3rd and 4th columns of the above table represent the double intervals.

The accuracy of settings for the arc lines is greater than for the solar lines, the mean probable error of an arc line from five settings being ± ·00018 Å and for a solar line ± ·00024 Å. With the best arc lines the error does not exceed ± ·0001 Å, which on the scale of the plate measured is equivalent to ·0003 mm. × 2 = ± ·0006 mm. This extraordinary degree of precision may be easily attained by paying attention to certain details of manipulation both in taking the original photographs and in copying them. As the best results for unsymmetrical lines are got by photographically reversing the positive with reference to the negative and not reversing the spectrum end for end, it follows that the positive images on one side of the spectrum will be superposed on the negative images on the opposite side, and unless the images are of equal density on both sides the sensitiveness of the adjustment for coincidence will be greatly impaired. In taking the original photograph therefore care should be taken to ensure this equality of density. For direct current and a steady arc it is sufficient to reverse the poles during the exposure so that positive and

negative poles change places with reference to the spectrograph slit, and an equal exposure is given in each position. This will also correct any very small change of wave-length which may be suspected in the radiation from positive or negative pole.

In making the positive and negative enlargements for measurement it is, as already mentioned, essential that both shall have the same gradation of tone; at any rate for the lines to be measured. In many cases the variation of density for the different lines is so great that it is difficult or not possible to obtain a positive which is the exact counterpart of the negative, but with ordinary care in development the positive may be made to exactly neutralise the negative for a large proportion of the lines. The "fit" of the plates may be tested immediately after fixing by sliding the positive on the negative film to film while wet, and holding up to the light. In measuring, good results cannot be obtained unless the movement of the micrometer is perfectly smooth and without appreciable "backlash". Ordinary spectrum micrometers leave very much to be desired in this respect; there is considerable friction in the gunmetal slide, and unless this is constantly attended to and cleaned the movement becomes irregular with much lost motion in parts of the slide where the oil has become thick, or dust has accumulated. The apparatus I have adapted for use with the micrometer is to be regarded as a preliminary makeshift, useful for ascertaining the possibilities of the method, I have little doubt that still greater accuracy could be attained if the micrometer were specially designed for the purpose. It would be better for instance to have a fixed microscope and slide for the positive, and mount the negative on a carriage moving on wheels. With a practically frictionless movement the lost motion could be reduced to an infinitesimal amount and the wear on screw and nut would be greatly lessened.

KODAIKANAL,
29th July 1913.

J. EVERSHED,
Director, Kodaikanal and Madras Observatories.

(33)

Kodaikanal Observatory.

BULLETIN No. XXXIII.

PROMINENCE PERIODICITIES.

BY T. ROYDS, D.Sc.

The half-yearly data of prominences and Hα markings prepared for the Kodaikanal Observatory Bulletins lead one to suspect regular variations of short period in them. In order to investigate the matter more fully it was resolved to construct the periodogram of prominences in the same way that Schuster has done for sunspots.*

2. Any investigation of periodicities must be based on fairly complete and uniform data. At Kodaikanal visual observations have been maintained on a uniform plan since February 22nd, 1904, and the spectroheliograph has been in continuous use from December 1904, since when both visual and photographic observations have been available. The observations from January 1905, may therefore be taken as a sufficiently uniform series and have been used in this investigation. As for their completeness it may be stated that since 1905, the average number of days in the year on which the prominences observations have been made is 298, the lowest being 269 in 1906, and the highest 312 days in 1910.

3. The total prominence areas for each month for the years 1905 to 1912, have been got out from the observatory records, and the mean daily areas obtained by dividing by the effective number of days of observation in each month. This effective number of days has been arrived at by marking a day on which the conditions of observation were not good as ¾, ½ or ¼ day according to the quality of the sky and definition at the time of observation. The data are given in Table I.

TABLE I.

Kodaikanal { Total Prominence Areas in Square Minutes / Effective number of days of Observation / Mean daily Prominence Areas in Square Minutes } for each month.

Year.	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct	Nov.	Dec.
1905	116·8 24½ 4·76	127·6 24 5·31	167·7 25¼ 6·62	103·4 23¼ 4·45	123·0 25¼ 4·86	81·1 19¾ 4·10	100·6 19½ 5·16	127·2 20½ 6·21	77·0 16 4·81	111·8 18½ 6·02	79·9 15¼ 5·23	101·0 24¾ 4·09
1906	144·4 26 5·55	167·4 25¾ 6·50	140·4 26¾ 5·25	122·3 23½ 5·20	127·4 25¾ 4·95	39·5 12½ 3·16	36·1 12¼ 2·95	32·0 11¼ 2·85	48·6 18¼ 2·66	50·3 19½ 2·58	30·6 13¾ 2·22	68·8 16½ 4·16
1907	149·3 27 5·51	150·9 26½ 5·70	181·5 29¾ 6·10	120·8 22½ 5·38	136·2 28¼ 4·82	54·3 16¼ 3·34	64·1 12¾ 5·03	69·1 12¾ 5·42	94·6 21 4·50	107·6 18¾ 5·72	58·3 13 4·49	106·0 25½ 4·15
1908	168·7 25½ 6·61	136·8 21½ 6·36	254·6 25 10·20	226·9 27¼ 8·33	203·8 28¾ 7·10	103·6 16¼ 6·37	58·8 11 5·33	111·4 21¼ 5·25	77·0 19¼ 4·00	107·2 17¼ 6·20	121·3 24½ 4·95	101·3 21½ 4·70
1909	119·8 21½ 5·57	138·2 24¼ 5·70	157·2 28¼ 5·56	124·2 24 5·18	116·2 22 5·29	76·6 15¼ 5·01	36·9 9½ 3·88	86·1 15½ 5·55	100·4 21 4·79	89·0 21½ 4·14	90·6 21¾ 4·16	101·4 23¾ 4·26
1910	97·0 22 4·40	124·2 23½ 5·29	182·0 30 6·06	110·4 29 3·81	179·4 26¾ 6·70	55·8 13¼ 4·21	81·9 13¾ 5·95	55·0 13½ 4·07	64·5 15½ 4·16	90·4 20½ 4·40	91·5 17 5·38	125·2 30 4·17
1911	72·8 23½ 3·10	86·0 25¼ 3·40	75·2 28¼ 2·66	105·1 24¼ 4·34	58·2 23 2·53	58·1 16½ 3·53	27·5 9¼ 2·98	67·2 20 3·36	63·2 19½ 3·24	72·8 19 3·83	86·2 16¾ 5·15	70·4 16¼ 4·33
1912	93·6 27½ 3·40	91·2 24¾ 3·69	60·4 25½ 2·37	63·6 22 2·89	45·5 22 2·07	40·4 7¼ 5·57	27·4 8 3·42	51·4 12½ 4·11	47·6 18 2·65	34·0 11½ 2·95	51·2 14½ 3·54	70·6 22¼ 3·17

* Schuster, Phil. Trans. Roy. Soc. A. vol. 206, p. 69, 1906.

4. The periodogram reproduced in Fig. 1 on page 30 was obtained from the mean daily areas for each month from 1905 to 1912, by first calculating the Fourier coefficients of the periods of 12, 13,.........up to 22 months, and the first, second, and in some cases the third sub-periods. The ordinate of the periodogram is then proportional to the product of the sum of the squares of the Fourier coefficients and the time interval to which the Fourier analysis has been applied.* As the interval 1905 to 1912 does not include more than 5 complete periods of 19 months the curve was carried only so far beyond this point as to show whether the incipient rise was continued. The ordinates of the periodogram, and the phases at 1905·04 are given in Table II, the phase being 0° when the period has its maximum.

TABLE II.

Ordinates of the Periodogram (*S*) *and Phases* ϕ.

Period in months.	S.	ϕ	Period in months.	S.	ϕ
$3\frac{3}{4}$	30	1°	8	748	1°
4	249	153°	$8\frac{1}{2}$	228	286°
$4\frac{1}{3}$	0	295°	9	174	58°
$4\frac{1}{2}$	82	28°	$9\frac{1}{2}$	36	197°
4·8	132	231°	10	23	16°
5	49	14°	$10\frac{1}{2}$	406	209°
$5\frac{1}{3}$	166	105°	11	2130	37°
$5\frac{1}{2}$	64	344°	12	2806	61°
$5\frac{2}{3}$	422	178°	13	3790	5°
6	588	104°	14	8831	295°
$6\frac{1}{3}$	2150	29°	15	1012	212°
$6\frac{1}{2}$	716	318°	16	182	38°
$6\frac{2}{3}$	105	289°	17	30	295°
7	248	263°	18	368	1°
$7\frac{1}{3}$	1343	108°	19	729	141°
$7\frac{1}{2}$	1675	57°	20	455	249°
$7\frac{2}{3}$	1060	22°	21	200	50°

It is seen that the prominence periodogram shows the presence of three periods of large intensity, two nearly homogeneous, of $6\frac{1}{3}$ and $7\frac{1}{2}$ months and a third, which is provisionally fixed at $13\frac{1}{3}$ months as being probably the highest point of the band.

The times of maxima are as given below in Table III.

TABLE III.

Period.		Times of Maxima.
$13\frac{1}{3}$ months	... ...	1912 October 4 $\pm$ n. $13\frac{1}{3}$ months.
$7\frac{1}{2}$ „	... ...	1912 August 22 $\pm$ n. $7\frac{1}{2}$ months.
$6\frac{1}{3}$ „	... ...	1912 June 21 $\pm$ n. $6\frac{1}{3}$ months.

5. Before proceeding to discuss this periodogram, it is necessary to consider whether the periods indicated above have not been introduced into the data in deriving the mean daily areas. It is clear that unless the days of incomplete observation have been exactly allowed for, a periodicity in the number of days of observation will cause the same periodicity in the daily areas, of an intensity depending on the exactness with which the allowance can be estimated. It was consequently foreseen that there might appear in the daily areas from this cause, at least one period, namely 12 months owing to the annually recurring monsoons. In order to remove all doubts as to what periodicities might be introduced in this way, I have constructed the whole periodogram of the effective number of days of observation. This curve, which is also given in Fig. 1, has a peak at 12 months, which shows that unless the allowance for partial days has been strictly exact, the prominence periodogram ought to be raised or lowered at this point. The curve of effective days of observation also shows peaks as subperiods of the annual period, namely at 6·0 months and 4·0 months, but these are inconsiderable.

* Schuster Proc. Roy. Soc. A. vol. 77, p. 136, 1906.

I have shown therefore that the periods in the mean daily prominence areas of $6\frac{1}{3}$, $7\frac{1}{2}$ and $13\frac{1}{3}$ months are not due to periodicities in the number of days of observation. Consequently it is of no immediate importance to estimate the effect of a possible under- or over-allowance for the days of incomplete observations, but whether the allowance has been under- or over-estimated can be tested by considering the phases of the period in the number of days of observation and of the *resulting* period in the daily areas. For, during poor observing months when the number of days of observation is small, the effective number of days is too large if the allowance for partial days is under-estimated and consequently the daily areas too small. That is, the areas are too small when the number of days of observation is small, or in other words the phases are coincident. Similarly, when the allowance is over-estimated the phases are opposite. For instance, if I under-estimate the effect of partial days by making no allowance at all, the phase of the annual period in prominences is 56°, nearly coincident with 53° for the number of days of observation, whereas after making the estimated allowance it is 61°. It seems therefore that the allowance may still be under-estimated.

It should be pointed out that the scale of the periodogram of effective number of days of observation in Fig. 1 is an arbitrary one

6. The best proof of the reality of the periods which have been found in the Kodaikanal daily areas is their presence in the prominence data of other observatories. The "Memorie della Società degli Spectroscopisti Italiani" contain prominence data which, although dependent on less frequent observations and not including prominences less than 30″ high, extend for many years back. The mean daily frequencies for each month from 1881 to 1912, deduced from observations at Palermo and Catania, have been analysed and the resulting periodogram shows distinct peaks at the same points as the Kodaikanal curve, as shown in Fig. 1. Although the ordinates are much smaller than in the Kodaikanal curve, indicating that the periodicities may not have been active during the whole interval 1881—1912, and although other peaks (not shown in the figure) are present, these results strongly confirm those deduced from the Kodaikanal observations. In further confirmation we have the fact that the phases agree as well as could be expected for each of the three periods. This is shown in Table IV.

TABLE IV.

Period.	Phase at 1905·04 Kodaikanal.	Phase at 1905·04 Palermo-Catania.
$13\frac{1}{3}$ months	340°	12°
$7\frac{1}{2}$ "	57°	138°
$6\frac{1}{3}$ "	29°	59°

7. It is desirable to give an idea of the amplitudes of the three periods which have been found in the Kodaikanal observations. The average of the mean daily prominence areas for the whole interval is 4·64 square minutes and the amplitudes are the following percentages of this average, the range being double the amplitude :—

Period.	Amplitude as percentage of average of mean daily areas.
$13\frac{1}{3}$ months	13·6 %
$7\frac{1}{2}$ "	9·1 %
$6\frac{1}{3}$ "	10·1 %

We can obtain some idea of the ratio of these amplitudes to that of the 11 year period in prominences. The Palermo-Catania series extend over a sufficiently long interval to give an approximate value at least, of the amplitude of the 11 year period, and by a comparison of Kodaikanal and Catania observations during the years 1905 to 1912, it is seen that the 11 year period has a slightly smaller amplitude in Kodaikanal *areas* than in Catania *frequencies*. The amplitude of the $13\frac{1}{3}$ month period in the Kodaikanal data is, as a result of this comparison, about $\frac{1}{3}$ that of the 11 year period and the amplitudes of the $6\frac{1}{3}$ month and the $7\frac{1}{2}$ month periods are each about $\frac{1}{4}$.

8. Two of the periods found are near planetary periods of revolution. The sidereal period of Venus is 7·38 months and the synodic period of Jupiter 13·11 months; the synodic period of Venus is 19·19 months, but the slight rise of the periodogram at this point has probably no real significance. Considerations of

phase show, however, that these coincidences are probably accidental. The maxima of the period of 7·38 months occur when Venus is about its ascending node, and the maxima of the 13·11 month period, when Jupiter is in eastern quadrature. If the coincidences are real, the causal connection must be an obscure one in view of these facts.

9. I have shown that three periodicities namely of $13\frac{1}{3}$, $7\frac{1}{2}$ and $6\frac{1}{3}$ months exist in the prominence areas as observed at Kodaikanal from 1905 to 1912 and have obtained some confirmation of them from the long series of Italian observations. Other independent prominence data which are sufficiently complete and continuous are, however, highly desirable in order to establish firmly the reality of these periods.

THE OBSERVATORY, KODAIKANAL,
August 18th, 1913.

T. ROYDS,
Asst. Director, Kodaikanal and Madras Observatories.

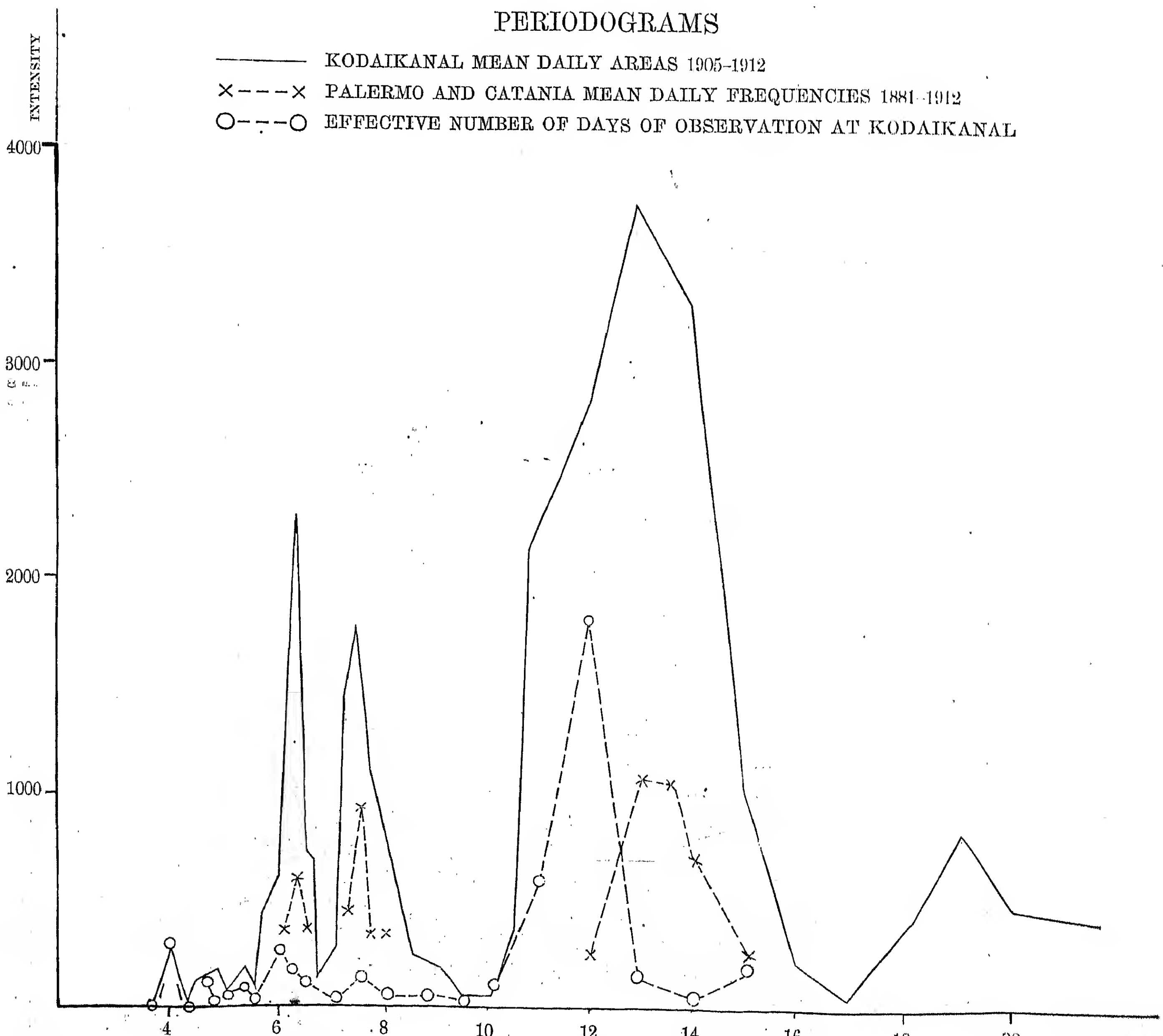


FIG. 1.

Kodaikanal Observatory.

BULLETIN No. XXXIV.

A COMPARISON OF THE PERIODICITIES IN PROMINENCES AND SUNSPOTS.

BY T. ROYDS, D.Sc.

I have already[1] determined the amplitude of the 11 year period in prominences for comparison with the amplitudes of certain short periods, notably one of 13⅓ months, which were found to exist in the prominence observations at Kodaikanal and Catania. When it was found further, as will be detailed below, that the short periods in prominences had no counterpart in sunspots, it became very desirable to determine whether the well-established sunspot periodicities other than that of 11 years, existed or not, in prominences. I therefore undertook the investigation of periodicities up to 11 years, by the periodogram method of Schuster[2] with the best data which were available for the purpose.

The data used are those published in the Memorie della Società degli Spettroscopisti Italiani based upon observations made by the Italian observers of all prominences exceeding 30″ in height. These observations extend from 1871 onwards, now embracing over 3 eleven-year cycles, and are the most complete and uniform series of prominence observations at present available for so long an interval. They are therefore the most suitable for the investigation of long periodicities. The quarterly and half-yearly values of the mean daily frequencies as tabulated in the Memorie della Società degli Spettroscopisti Italiani were used to determine the intensities of periods from 2 to 13½ years. The work was carried out in a manner similar to that which Schuster has worked out[2] and applied to the investigation of sunspot periodicities[3]. The two Fourier co-efficients were first determined for each period and its first, and sometimes the second, sub-periods. The ordinate of the periodogram is then proportional to the product of the sum of the squares of the Fourier co-efficients and the time interval to which the analysis has been applied[2]. The data were arranged to give the phase at the time of first datum of 1881, *i.e.* at 1881·25 for periods determined from the half-yearly values, or at 1881·125 for those determined from the quarterly values. The ordinates of the periodogram (S), and the phases (ϕ) determined from half-yearly values are given in Table I and from quarterly values in Table II. The phase is 0° when a period has its maximum.

TABLE I.

Ordinates of the Periodogram (S) *and Phases* (ϕ) *at* 1881·25.

Period in years.		S.	φ	Period in years.		S.	φ	Period in years.		S.	φ	Period in years.		S.	φ
6	...	5030	301°	7½	...	8895	156°	10	...	12970	128°	12½	...	22200	43°
6¼	...	1730	277°	8	...	9870	128°	10½	...	21900	122°	13	...	19830	32°
6½	...	2675	235°	8½	...	3667	113°	11	...	28500	95°	13½	...	16350	22°
6¾	...	2560	226°	9	...	4350	133°	11½	...	32200	77°				
7	...	8800	196°	9½	...	7510	136°	12	...	29250	64°				

TABLE II.

Ordinates of the Periodogram (S) *and Phases* (ϕ) *at* 1881·125.

Period in years.		S.	φ	Period in years.		S.	φ	Period in years.		S.	φ	Period in years.		S.	φ
2	...	808	114°	3⅛	...	970	138°	4½	...	2235	134°	6¼	...	3090	269°
2⅛	...	368	154°	3¼	...	1640	81°	4⅝	...	1127	84°	6½	...	2840	255°
2¼	...	579	358°	3⅜	...	784	35°	4¾	...	1680	119°	6¾	...	8500	221°
2⅜	...	44	162°	3½	...	230	16°	4⅞	...	1988	65°	7	...	7990	196°
2½	...	208	142°	3¾	...	440	70°	5	...	2505	96°	7¼	...	8900	178°
2⅝	...	1113	81°	4	...	383	338°	5¼	...	3995	69°	7½	...	9240	165°
2¾	...	539	299°	4⅛	...	1060	345°	5½	...	3845	21°	7¾	...	10400	146°
2⅞	...	37	199°	4¼	...	1145	203°	5¾	...	4343	346°	8	...	10650	133°
3	...	172	203°	4⅜	...	554	143°	6	...	3645	308°	8¼	...	7165	116°

[1] Royds, Kodaikanal Observatory Bulletin No. XXXIII. [2] Schuster, Proc. Roy. Soc. A., Vol. 77, page 136, 1906.
[3] Schuster, Phil. Trans. Roy. Soc., Vol. 206, page 69, 1906.

The periodogram is plotted in Figs. 1 and 2 below. Fig. 1 is the part from 5 to 13½ years and Fig. 2 shows the portion below 6½ years on an enlarged scale.

2. The predominant feature of the periodogram is, of course, the 11 year period, of which the first sub-period (5·56 years) but not the second, is well marked. Other features are the truncated peak from 6¾ to 8¼ years, which is probably composed of several periodicities, and small peaks at 4½ and 3¼ years.

———————— PERIODOGRAM OF PROMINENCES.

– – – – – – – – PERIODOGRAM OF SUNSPOTS [SCHUSTER].

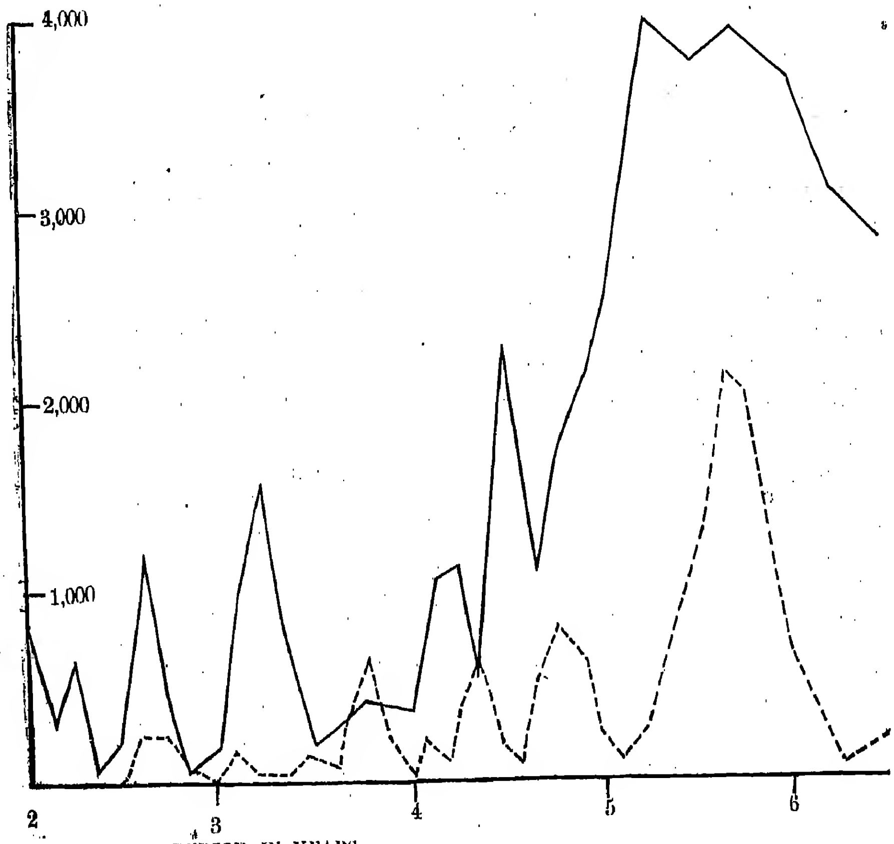


FIG. 2.

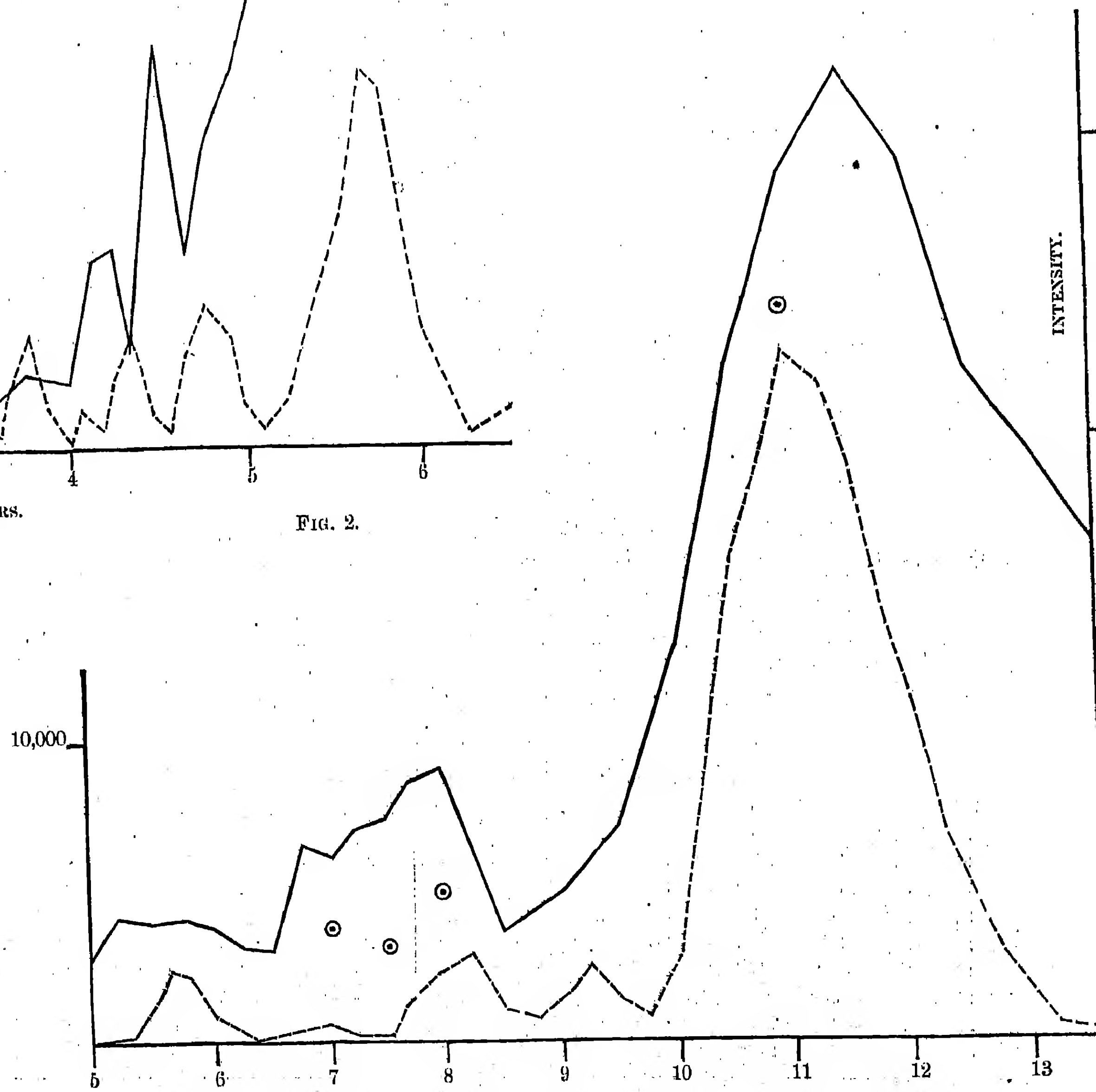


FIG. 1.

In order to facilitate comparison of the periodograms of prominences and sunspots I have added to Figs. 1 and 2, on a convenient scale, the sunspot periodogram as given by Schuster[1] for the years 1826–1900. This spot periodogram relates to a much longer time interval than that for which prominence observations are available, but this curve will serve for a general comparison. It is at once seen that the peaks of the 11 year period and its first sub-period are more pointed in the sunspot curve. This is of course due to the increase in what corresponds, in the optical analogy of the periodogram, to the resolving power brought about by the longer time interval and the greater reliability of spot data. It should here be mentioned that the slight dip at $5\frac{1}{2}$ years in the band of the prominence periodogram due to the first sub-period of the 11 year period has no real significance. When so short a time interval as the present is being analysed, fictitious discontinuities are likely to be introduced in the presence of homogeneous periods, by the relatively large variations of the time interval into which the intensity is multiplied to give the ordinate of the periodogram.

3. We now turn to a discussion of the individual periods which have been established for sunspots.—

(*a*) 11 *year period.*—The interval of 3 cycles is not sufficient to determine as accurately as may be desired the exact period in the neighbourhood of 11 years, but there can be little doubt that the true period in prominences is coincident with that of sunspots which Schuster has fixed at 11·125 years. Before proceeding to discuss the phases of the 11 year period it may be mentioned here that Riccò has recently[2] published a discussion of the same data on which the periodogram I have constructed is based. He finds, *inter alia*, that the maxima of prominences occur 2 years later than sunspots in two cases and one year previously in the third. How far this is due to a delay in the 11 year maximum can now be determined from the phase of the 11 year period. Assuming the true period to be 11·125 years, we deduce from the phases given in Tables I and II the following times of maxima for that period and its first sub-period. The phases for sunspots according to Schuster are given for comparison :—

Period.	Dates of Maxima in Prominences.	Dates of Maxima in Sunspots.
11·125 years	1906·3 ± n. 11·125	1905·31 ± n. 11·125
5·56 "	1903·6 ± n. 5·56	1903·75 ± n. 5·56

It is seen that the 11 year period has its maxima about one year later in prominences than in sunspots whilst the maxima of first sub-periods are practically coincident. Of course, it must be remembered that the 11 year periodicity in prominences is based on 3 cycles only and may therefore be considerably in error, but the phases are deduced from several neighbouring points in the band.

The effect of the greater retardation of the main period relative to the first sub-period is to flatten out the maximum of the 11 year cycle thus extending the duration of great activity of prominences. This retardation of the main period and the flattening out of the maximum is seen from Fig. 3, which shows the average growth and decay of prominences during the 11 year cycle, compared with the curve for Greenwich sunspot areas, on a convenient scale, for the same time interval.

CURVES OF GROWTH AND DECAY DURING 11 YEAR CYCLE.

A. PROMINENCES 1880—1912.

B. SUNSPOTS 1879—1911.

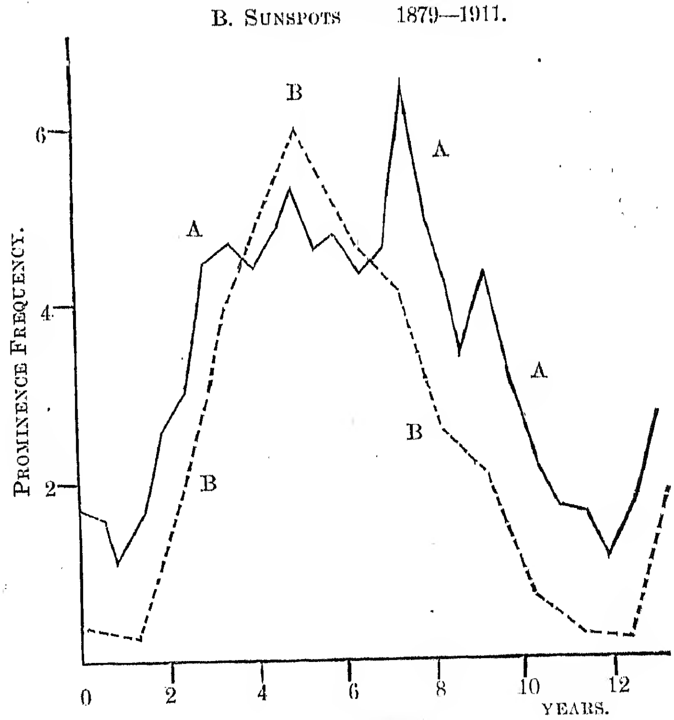


FIG. 3.

[1] Schuster, Phil. Trans. 206. 69. 1906. Table IV, column IV, and Table V.

[2] Riccò, Mem. Spett. It., Ser. II, Vol. II, page 147, 1913.

(*b*) *Periods of* 4·80, 8·36, 4·38 *years*.—None of these periods established for sunspots can be identified with certainty in the prominence periodogram. This is due in the more important cases to their being hidden, if present at all, in the broad bands due to other periods. The most persistent spot period, 4·80 years, for instance would be hidden in the band at 5½, and the 8·36 period in the band from 6¾ to 8¼ years. The less certain spot period of 4·38 years, may be identical with the peak at 4½ years in the prominence periodogram. If this is really so, the maxima in prominences occur at 1896·4 ± n. 4·38, rather earlier than in sunspots, where they are at 1897·00 ± n. 4·38 years. This comparison of phase is however hardly warranted in view of the uncertainty of the assumed identity of the periods in spots and prominences.

4. There are other periods in the prominence periodogram which have no counterpart in Schuster's curve for sunspots. The most important are those periods which are not distinctly resolved in the band from 6¾ to 8¼ years. The intensities of these periods are too large to be accidental, being indeed, after the 11 year period the most marked feature of the periodogram. Although the 8 year period may be affected by the spot period of 8·36 years the rest of the band is totally absent from the sunspot periodogram. It seems therefore, as though there was here a real difference in the periodicities in sunspots and in prominences. This conclusion is not warranted, however, until these periods are shown to be absent from sunspots in the time interval 1880—1912 for which the prominences are analysed; for it is possible that they might have been present in spots also for so short an interval but absent at other times, thus giving a small average intensity over the long interval 1826—1900 to which the spot periodogram relates. I have therefore determined the intensity of the periods of 7, 7½, and 8 years from the yearly values of the Greenwich daily sunspot areas from 1880—1911, and the relative intensities are given below, the points being marked thus ⊙ in Fig. 1, on a scale to show their true importance compared with the 11 year period. The values are given below together with those for prominences for comparison :—

Period.	Relative intensity.		Phases in spots at 1881·125.	Phases in prominences at 1881·125.
	In spots.	In prominences.		
11 years	1	1	...	...
8 „	0·19	0·38	135°	133°
7½ „	0·12	0·32	149°	165°
7 „	0·16	0·28	217°	196°

From the table we see that there can be no doubt in consideration of the agreement of phases (which, since they refer to the same time interval, are strictly comparable whatever the true periods may be) that identical periodicities exist in both sunspots and prominences, although their relative intensities are doubled in prominences.

It is seen therefore that there are within the region 7 to 8 years periods of considerable intensity n sunspots for the time interval 1880—1911, but since their average intensity during the interval 1826—1900 is small we must conclude that these periods are not permanently active. So far then as the periods between 6¾ and 8¼ are concerned there is no marked real difference between the sunspot and prominence periodograms, since if the spots and prominences are analysed for the same time interval, the same periodicities are found in each.

The period of 3¼ years which is also absent from the spot periodogram cannot, in view of its small intensity, be regarded as certain. We must conclude therefore that all the periodicities which can be established in prominences are present also in sunspots.

5. It is very evident from an inspection of spot and prominence data, that at the times of minimum solar activity, the activity of spots sinks much lower than that of prominences. In the following table are given the relative amplitudes of the periods which have been found, expressed as a percentage of the average value of the daily prominence frequency over the whole time interval, and compared with the corresponding data for spots :—

Period.	Amplitude in Prominences. (Average daily frequency 3·73.)	Amplitude in spots. (Average daily area 562.)
11·125 years	44% of average frequency.	73% of average area.
5·56 „	18% „ „	17% „ „
4·5 „	13% „ „	......
$6\frac{3}{4}$ to $8\frac{1}{4}$ „	28% „ „	33% of average area.

Short Periods.

6. Periodicities between 4 and 19 months have already been investigated in the prominence observations made at Kodaikanal during the years 1905 to 1912[1]. It is convenient here to summarise our knowledge of the existence of short periods in prominences. In the Kodaikanal observations was found a period of $13\frac{1}{3}$ months with an amplitude about $\frac{1}{3}$ that of the 11 year period as well as two others, less certain, of $7\frac{1}{2}$ and $6\frac{1}{3}$ of amplitudes each about $\frac{1}{4}$. The $6\frac{1}{3}$ month period may be partly due to the sub-period of $13\frac{1}{3}$ months. If we take the Catania prominence observations for the same interval, we find that the first two periods have amplitudes of about $\frac{1}{5}$ of the 11 year period, but the $6\frac{1}{3}$ month period is absent. The phases are not in good agreement, but the Catania observations are not so complete as those made at Kodaikanal where prominences below 30″ are taken into account. When we consider the longer interval of Italian observations 1880—1912, the average amplitudes are then small although the phases agree well with those derived from Kodaikanal observations. It appears, therefore, that the short periods mentioned are not permanent, but are in evidence only a comparatively short time.

SUNSPOT PERIODOGRAMS.

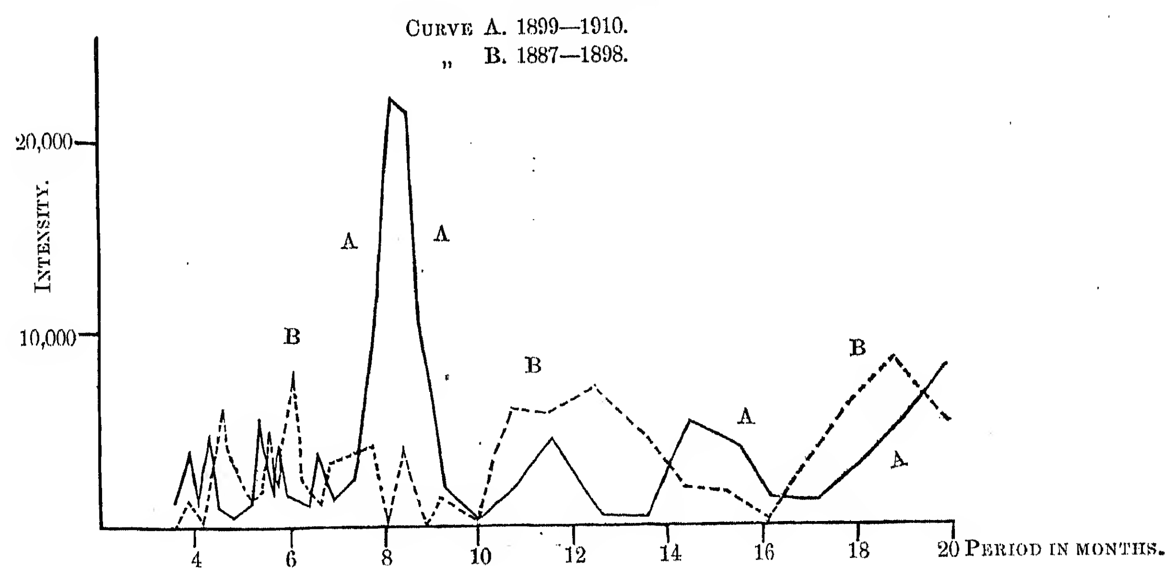


FIG. 4.

7. For the purpose of comparing these periodicities with those in sunspots, Mr. A. A. Narayana Ayyar, B.A., of this Observatory, has analysed sunspot data for short periodicities. The Greenwich data for each rotation of the sun were divided into intervals of about 12 years, the last of which, 1899—1910 includes the interval for which Kodaikanal prominence observations have been analysed. The periodogram for 1899 to 1910 was constructed first, and it was found that the 13 month period of prominences was entirely absent but a new one of just over 8 months was intense, having an average amplitude during these thirteen years of about $\frac{1}{3}$ that of the 11 year period. On passing to the previous twelve years 1887—1898 however the intensity of the 8 months period was practically zero and also small during the interval 1874—1886. The periodograms of the two first mentioned intervals are given in Fig. 4 above. It was found on closer

[1] Royds, Kodaikanal Observatory Bulletin No. XXXIII.

investigation that this period of about $8\frac{1}{4}$ months was present from 1892—1896 and reappeared again from 1903 to 1910 with the same phase as before. From the years 1874 to 1892 its appearance in proper phase has not been detected.

With regard to existence of the 13 month period in spots even when the interval 1905 to 1911 was analysed separately its amplitude was still not large. We see then that so far as these short periods are concerned, they are not simultaneously present in both spot and prominences; they appear in each for a short time only and then disappear and perhaps reappear again.

SUMMARY.

A.—Long Periods.

1. The prominence periodogram is very similar to that of spots for the same time interval. Between 2 years and 11 years there are no periodicities present in prominences which can be proved to be absent from sunspots, and *vice versâ*.

2. The 11 year period is the predominant feature of the prominence periodogram, and its maxima occur about one year later than in sunspots. The maxima of its first sub-period, 5·56 years, are not delayed in prominences.

3. Periods between 7 and 8 years of considerable intensity in prominences have been shown to be present also in spots, but they are not permanently active.

B.—Short Periods.

1. A period of 13 months in prominences from 1905—1912 is not present in spots and one of $8\frac{1}{4}$ months in sunspots is absent from prominences. These periodicities are not permanent but the spot period of $8\frac{1}{4}$ months has been shown to disappear for a time and reappear again later.

I wish to express my obligations to Mr. A. A. Narayana Ayyar, B.A., Third Assistant of this Observatory for his careful determination of short periodicities in sunspot data.

Kodaikanal Observatory,
November 13th, 1913.

T. ROYDS,
Assistant Director.

Kodaikanal Observatory.

BULLETIN No. XXXV.

THE APPARENT EFFECT OF PLANETS ON THE DISTRIBUTION OF PROMINENCES

BY

T. ROYDS, D.Sc., AND S. SITARAMA AYYAR, B.A.

In Kodaikanal Bulletin No. XXVIII, Mr. Evershed has shown that during the years 1904—1912 a larger number of prominences has been observed on the eastern limb of the sun than on the western, according to the observations made at Kodaikanal as well as those made at Catania and Kenley. This led to the supposition that the earth exerts an extinguishing influence during the transit of prominences across the disc thus producing an unequal distribution at the two limbs, and similar effects were looked for in the cases of the other planets. Mr. Evershed concluded that there was slight evidence of planetary action similar in effect to that of the earth in the case of Venus only among the major planets.

2. It seemed to us that the periodogram method of Schuster * would afford a means of deciding definitely and conclusively for, or against, planetary influence. For, if any planet exerts an appreciable influence on the relative numbers on the east and west limbs, there will not only be a well marked periodicity coincident with the synodic period of revolution of the planet but also a second criterion will be afforded, namely, the phase of the period must bear some interpretable connection with the relative positions of the earth, sun and planet.

3. The periodogram which is reproduced in Fig. 1 on page 38 was constructed from the Kodaikanal observations of the number of prominences seen on the eastern limb, expressed as a percentage of the total, for each month of the years 1904—1913, June. The two Fourier co-efficients were calculated for periods of 12, 13, 14, ... up to 24 months and of the first and second sub-periods of each. The ordinate of the periodogram is then proportional to the product of the sum of the squares of the Fourier co-efficients and the time interval to which the analysis has been applied.* The ordinates of the periodogram and the phases at 1904 January 15 (0° at maximum) are given in Table I.

TABLE I.

Ordinates of Periodogram (S) and Phases (φ) at 1904·04.

Period in months.	S.	φ	Period in months.	S.	φ	Period in months.	S.	φ
$3\frac{1}{2}$	0·03	306°	7	0·07	3°	13	1·33	177°
$3\frac{3}{4}$	0·79	134°	$7\frac{1}{3}$	0·34	249°	14	0·11	97°
4	0·12	359°	$7\frac{1}{2}$	0·11	164°	15	0·03	148°
$4\frac{1}{3}$	0·84	242°	$7\frac{2}{3}$	0·08	359°	16	0·00	289°
$4\frac{2}{3}$	0·30	299°	8	0·34	229°	17	0·17	179°
$4\frac{4}{5}$	0·19	178°	$8\frac{1}{2}$	0·15	29°	18	0·11	106°
5	0·27	167°	9	0·06	313°	19	0·02	135°
$5\frac{1}{3}$	0·19	312°	$9\frac{1}{2}$	0·17	242°	20	0·28	265°
$5\frac{2}{3}$	0·11	86°	10	0·00	272°	21	0·45	211°
6	0·34	20°	$10\frac{1}{2}$	0·20	334°	22	0·46	155°
$6\frac{1}{3}$	0·53	235°	11	0·68	285°	23	0·21	153°
$6\frac{1}{2}$	0·11	141°	$11\frac{1}{2}$	0·77	255°	24	0·09	97°
$6\frac{2}{3}$	0·20	171°	12	0·87	226°			

* Schuster, Proc. Roy. Soc., A-77, 136, 1906.

The periodogram (Fig. 1) shows maxima at 13, $4\frac{1}{3}$ (second sub-period of 13 months), $3\frac{3}{4}$, 6, and about $21\frac{1}{2}$ months. Of these, the 13 months period is possibly the only real one.

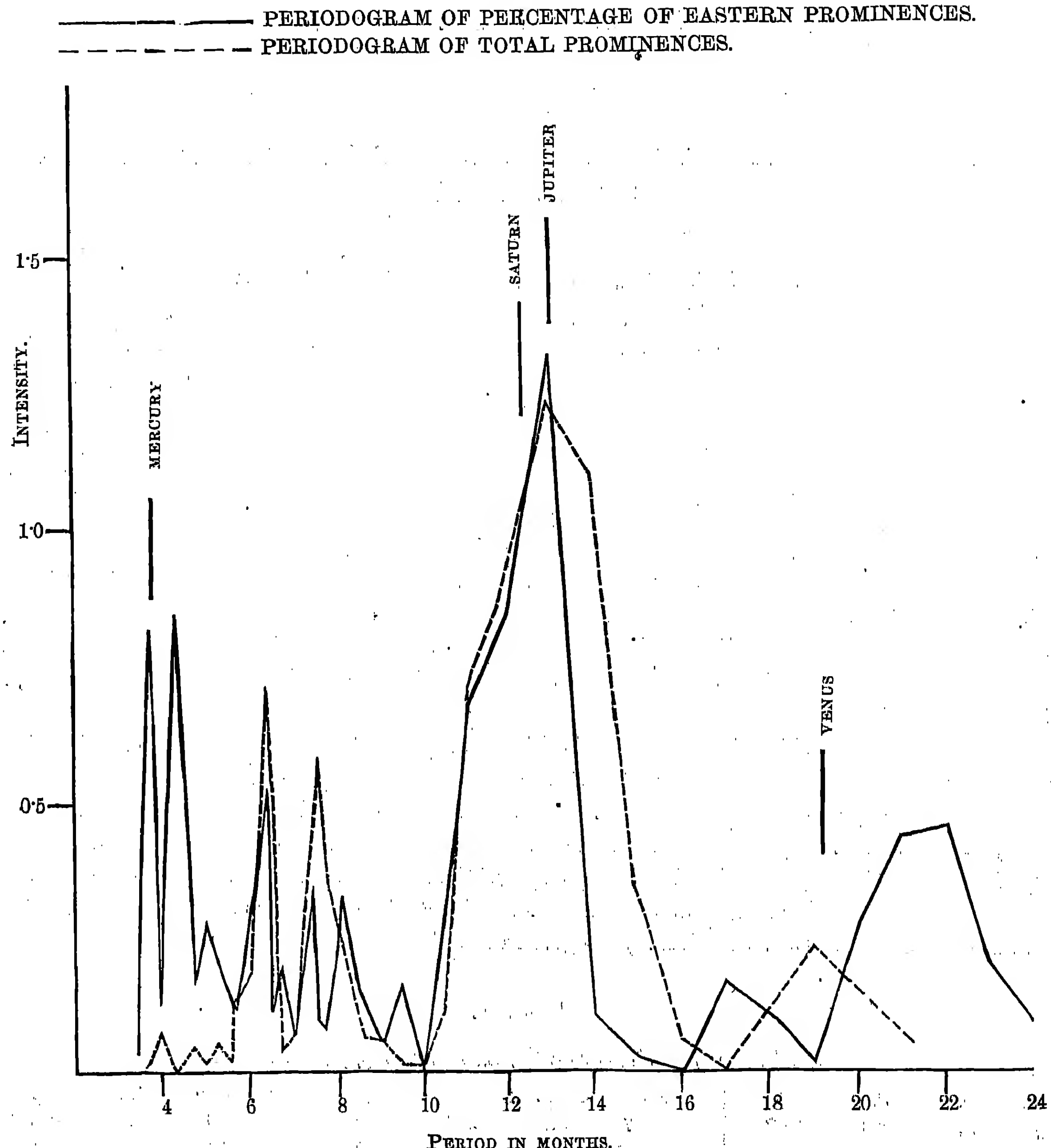


FIG. 1.

The synodic period of revolution of several planets are marked in the figure and at these points there would be a peak in the curve if the corresponding planet exerts any influence on the relative number of prominences on the east and west limbs.

It is seen that the ordinate of the periodogram is large near the periods of Jupiter (13·11 months) and of Mercury (3·81 months). The more distant planets Saturn, Uranus and Neptune have their synodic period slightly larger than 12 months, whilst the influence of the earth, if variable, would give rise to an annual period. The effect, if any, of the planets Saturn, Uranus, Neptune and Earth is therefore superposed in the band whose highest point is at 13 months.

Mr. Evershed obtained evidence of a slight indication of an influence exerted by Venus, but the evidence of the periodogram is entirely against it, for at 19·19 months, the synodic period of Venus, there is no suggestion whatever of a rise in the curve. This contradiction requires some explanation which probably lies in the fact that Mr. Evershed considered only the times near superior and inferior conjunctions whereas

the method of harmonic analysis includes the whole revolution. In fact, a gradual extension of the limits between which the values are taken very soon reduces the apparent effect of Venus. The following table shows that when the prominence numbers for times between 56° on each side of the positions of conjunction are taken the apparent effect of Venus is practically zero.

Distance of limits on each side of positions of conjunction.	Average per cent. of eastern prominences near inferior conjunction.	Average per cent. of eastern prominences near superior conjunction.	Difference.
19°	53·61%	52·19%	1·42%
30° *	53·90% *	52·56% *	1·34%
37°	52·82%	52·31%	0·51%
56°	52·60%	52·61%	−0·01%

It is, however, not inconsistent with these facts that the combined effect of Venus and Earth becomes appreciable only when their difference in longitude is very small when a rapid increase of effect might take place, quickly dying away again as the planets separate. We have therefore constructed Fig. 2, giving the average number of eastern prominences during the revolution of Venus, to show that such an effect cannot be large.

CURVE OF PERCENTAGE OF EASTERN PROMINENCES DURING SYNODIC REVOLUTION OF VENUS.

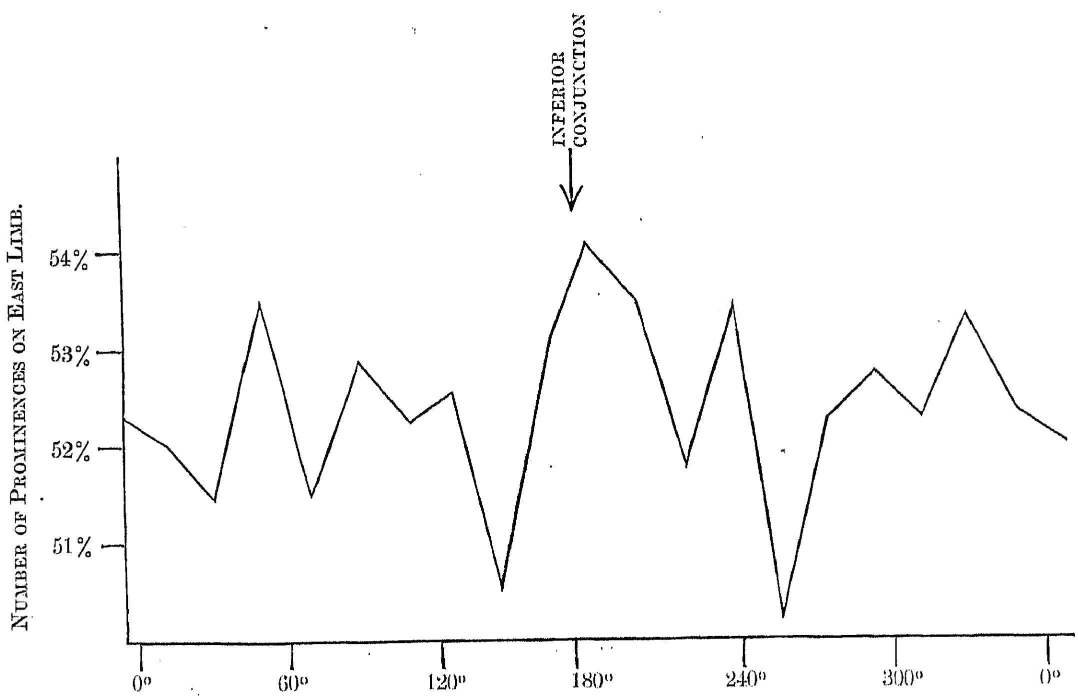


FIG. 2.

The remaining results deduced by Mr. Evershed are interpreted by the periodogram as follows :—

(*a*) The absence of any effect due to Jupiter is due to the fact that the 13 month period has its zero values about the times of conjunctions of Jupiter (its maxima occurring about the times of quadrature as determined below).

(*b*) The apparent effect of Saturn is due to its period (12·4 months) falling within the 13 month band, as also does the annual period.

* Given by Evershed, Kodaikanal Observatory Bulletin, No. XXVIII.

4. Considerations of phase will now give some indication of the probability of the apparent effect of Jupiter and Mercury being real.

The phase of the Jupiter period (13·11 months) can be calculated from the phase of the trial periods near it, and is, at the date of 1904 January 15, about 165°. Consequently the maxima occur at the times 1904 July $1 \pm n \times 13{\cdot}11$ months. If there is a real effect of Jupiter similar to that supposed to be exerted by the earth, we should expect the dates of maxima to be near the times of the oppositions of Jupiter. The oppositions occur, however, at 1904 October $19 \pm n \times 13{\cdot}11$ months. So large a lag as this, 260° or 9·5 months, does not seem probable. The times of maxima are, indeed, nearly coincident with the dates of western quadrature of Jupiter and it is difficult to suppose a real influence of Jupiter such that the planet would exert its maximum effect in this position.

The phase of the 3·81 month period of Mercury can be determined less accurately than that of Jupiter but would be at the same date 1904 January 15, about 61°, the maxima occurring, therefore, at 1904 February $1 \pm n \times 3{\cdot}81$ months. The maximum effect of Mercury would be expected at the times of inferior conjunction, 1904 January $17 \pm n \times 3{\cdot}81$ months which represents a lag of 47°, or 15 days. It is not likely, therefore, that there is a real effect due to either Jupiter or Mercury.

Further, if the effect of a planet is proportional directly to its mass and inversely to some power of its distance from the sun (as for instance a tidal effect), then since the supposed effect of Mercury is comparable with that of Jupiter, the effect cannot diminish more rapidly than as the inverse third power of the distance, and consequently we should expect the effect of Venus also to be appreciable. This is seen from Table II. The absence, however, of any effect due to Venus as indicated above, points against the reality of planetary influence.

TABLE II.

*Relative Effect of Planets.**

Planets.	Effect $\propto m/d$.	Effect $\propto m/d.^2$	Effect $\propto m/d.^3$ (Tidal force.)	Effect $\propto m/d.^4$
Mercury	0·14	0·37	0·95	2·44
Venus	1·12	1·54	2·13	2·95
Earth	1·00	1·00	1·00	1·00
Mars	0·07	0·05	0·03	0·02
Jupiter	60·45	11·62	2·23	0·43
Saturn	9·86	1·03	0·11	0·01

We have concluded from this evidence that it is not likely that any of the planets have an influence on the relative number of prominences on the eastern and western limbs, and that therefore an influence exerted by the earth is improbable.

5. The band in the periodogram from 10 to 14 months at once reminded us of the similar band in the periodogram of the total prominence areas.† In order to facilitate comparison, the periodogram of the total prominence areas has been added to Fig. 1, on a suitable scale. There is a striking similarity between the two periodograms in that the main feature of each is a band at 13 months. The sub-period (4½ months), is absent from the total prominences but the peak near 6 months is reproduced. Let us now consider the phase of the periods common to the two periodograms. Since they both relate to almost exactly the same time interval the phases of the same trial periods are strictly comparable whatever the true periods may be. The phases of the periods of eastern prominences have been reduced to the epoch 1905 January 15, for comparison with those of the total prominences taken from Table I of the Kodaikanal Bulletin No. XXXIII. The differences of the phase are given below in Table III for the 13 month period and Table IV for the 6 month period.

* A similar table is given by Schuster, Proc. Roy. Soc. A-85, 309, 1911.

† Royds, Kodaikanal Observatory Bulletin No. XXXIII.

TABLE III.

Phases of Period near 13 months.

Trial Period.	11 months.	11½ months.	12 months.	13 months.
astern prominences	253 °	237°	226°	205°
Total prominences	37°	89°	61°	5°
Difference of phase	216°	148	165°	200°

TABLE IV.

Phases of Period near 6 months.

Trial Period.	6 months.	6½ months.
Eastern prominences	20°	276°
Total prominences	104°	29°
Difference of phase	276°	247°

For the 13 month period, which is the most certain in both periodograms, the phases differ by approximately 180°, but this is not so for the 6 month period though the values are in this case less trustworthy. This fact does. however, point to the existence of a real connection between the two periodograms.

If the 13 month period in the relative number of eastern prominences is due to Jupiter, we should expect that it would be permanently active, whilst one of us has shown* that the 13 month period in total numbers has a small average intensity over a long interval from 1881—1912 according to the Italian data. Consequently we can test whether the connection between the two periods is a real one by examining whether the period in eastern prominences also disappears during the long interval. The Italian data are not so complete as may be desired for the purpose, giving frequently very large or very small values for the percentage at the eastern limb, but the evidence does point to the disappearance of the 13 month period since the average intensity over the years 1881—1912 is only ⅓ of that over the years 1904—1912.

6. It is perhaps necessary to make clear that the similarity of the two periodograms in Fig. 1 cannot be due to accidental variations in the number of eastern prominences. When there is the largest number of prominences, *i.e.*, at the times of maxima of the 13 month period, the number of eastern prominences would, if their variations were accidental, tend to approach their average value. At the times of minima of prominence activity, however, the eastern prominences would tend to have their large and small values and not systematically one or the other. Consequently the average intensity of the 13 month period due to accidental variations would be small.

The presence of the 13 month period in eastern prominences, opposite in phase to that in the total, means that the 13 month period is more intense in western prominences than in eastern. The amplitude in western prominences is not sufficient alone to cause the observed amplitude in the total prominences which amounts to 13·6 per cent. of the average value.

7. Some light is thrown upon the subject by studying the relative numbers of prominences north and south of the equator, for in this case also there is a systematic excess on the one side, namely, on the southern where there appear an average of 51·78 per cent. of the total number. The periodogram of the percentage number on the north of the equator at both limbs was constructed exactly similarly to that of the eastern prominences. The periodogram is shown in Fig. 3 below. It is at once obvious that there are no definite periodicities in the relative numbers north and south of the equator and that therefore the variations are chiefly accidental. This shows clearly, if proof were needed, that accidental variations in the number

* Royds, Kodaikanal Observatory Bulletin No. XXXIII.

of the eastern prominences, which would not be greater than in the number of the northern prominences, could not produce the similarity of its periodogram with that of the total numbers.

PERIODOGRAM OF PERCENTAGE OF NORTHERN PROMINENCES.

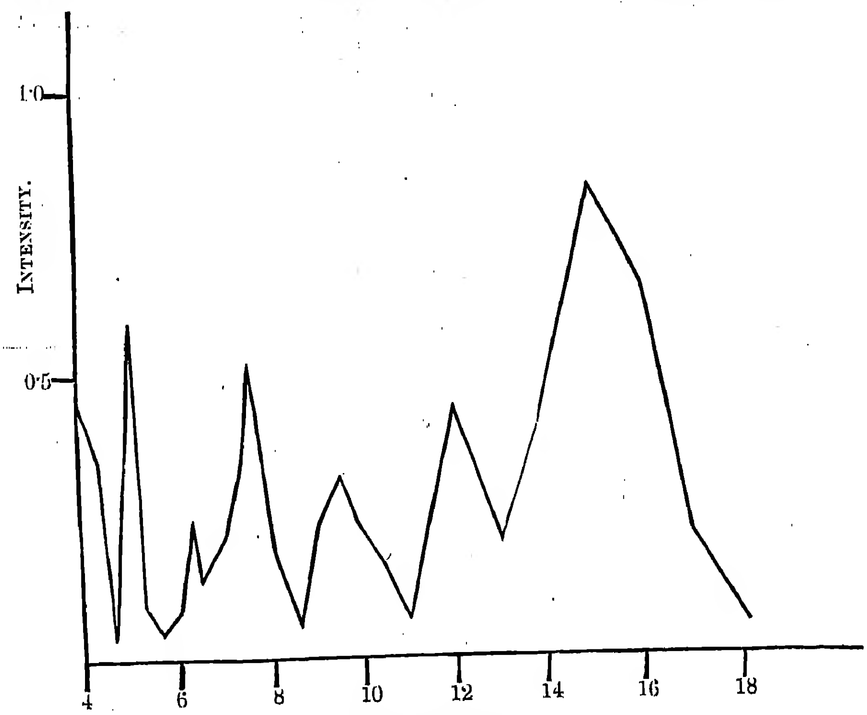


FIG. 3.

To what, then, is the southern excess due? Clearly not to planetary influence since there are no periodicities of less than 19 months present. The cause may lie within the sun itself and may possibly be due to the maxima of long period variations occurring during the time interval considered (1904—1913 June) but whose ultimate cause is still undetermined.

8. Relating to the excess of prominences on the eastern limb we have now the following facts awaiting explanation:—

(a) An average excess on the eastern limb for the years 1904—1912 discovered and discussed by Mr. Evershed.*

(b) A periodicity of 13 months in the variation of the eastern excess, probably identical with the 13 month period in the total number of prominences but opposite in phase. Periods of 4⅓ months (second sub-period of 13 months) and 3¾ months are also present but less important.

Although we have concluded that these periodicities are not due to planets, and consequently that an effect due to the earth is improbable, the *observed* systematic excess on the one limb, or any periodicity in its variations, must be associated with the earth's direction. In the absence of any influence exerted by the earth we are driven to the conclusion that the effects observed are produced by the rotation of the sun (and would be observed from whatever direction the sun were viewed) although Mr. Evershed deduced evidence on certain assumptions which pointed to the opposite conclusion. If the rotation of the sun is the true cause we do not see any obvious explanation of the 13 month periodicity and, although long period variations may be also present whose maxima occur during the interval considered, we should expect the eastern excess due to this cause to be permanent.

For the further study of these problems there is a lack of sufficiently complete prominence data for a long interval of time. It is greatly to be desired that not only should observations be made as frequently as possible, but that prominences below 30″ in height should be recorded in order to obtain values for the prominence activity of the sun as nearly true as possible.

* Evershed, *loc. cit.*

9. The similarity of the two periodograms seems to us to confirm the reality of the chief features of the periodogram in the total areas of prominences, for we know of no *a priori* reason except that stated in the second paragraph of section 6, why the percentage number on one limb should be dependent on the total. The confirmation is the more remarkable since the total prominence area per day depends on the number of days of observation, which introduces an element of uncertainty from which the percentage observed in the eastern limb is free, as the number of days of observation does not in this case come into consideration.

T. ROYDS,
Assistant Director.

S. SITARAMA AYYAR,
First Assistant.

KODAIKANAL OBSERVATORY,
15*th November* 1913.

Kodaikanal Observatory.

BULLETIN No. XXXVI.

A NEW INTERPRETATION OF THE GENERAL DISPLACEMENT OF THE LINES OF THE SOLAR SPECTRUM TOWARDS THE RED.

In Bulletin No. XVIII a rough estimate was attempted of the pressure in the reversing layer of the sun, based on the assumption that those lines which are most and least affected by pressure in the laboratory would also be similarly affected in the sun, so that a comparison of relative positions of the solar lines and the lines in the spectrum of the electric arc at atmospheric pressure should give a value of the pressure in the sun which would be independent of the absolute displacements of the solar lines which might be affected also by motion in the line of sight.

The result of a comparison of the iron arc wave-lengths measured by Kayser and the solar wave-lengths of Rowland, the only material then available, seemed to show clearly that if the above assumption is correct the pressure in the reversing layer could not exceed one atmosphere, the evidence tending to show indeed that the lines most affected by pressure are in the sun slightly displaced towards the violet relatively to those least affected by pressure, indicating a less pressure in the sun than in the iron arc in air.

This conclusion conflicts with estimates of the pressure based on the absolute shift of the solar lines to the red compared with the normal positions of those lines in terrestrial sources, such estimates indicating pressures up to five or six atmospheres.

I propose to show in this paper that taking into consideration probable differences of level the absolute and relative shifts can be quite easily explained as due to motion in the line of sight, and have very little relation to pressure shifts.

The relative shifts to the red of the lines in the spectrum of the sun's limb compared with the centre of the disc can also be much more readily explained as a motion shift, than as a pressure shift, although this interpretation involves an apparent influence of the earth on solar phenomena analogous to that which affects the distribution of sunspots and prominences. I shall give in a subsequent paper the results of our measures of the limb shifts and the conclusions to be drawn from them.

Since the introduction of the electric installation at Kodaikanal Observatory it has been possible to get direct measures of the absolute and relative shifts of the solar lines compared with those in the spectrum of the electric arc. It is evident that by directly confronting the arc and sun on the same plate, and measuring the absolute displacements, much more reliable results can be obtained than by comparing wave-length determinations of sun and arc by different observers

Although the quantities measured are exceedingly small and subject to considerable errors, the results of the investigation so far as it has gone are so strongly opposed to the view that pressure is the main factor in producing the solar line-shifts that I consider it proper to publish these results, notwithstanding the fact that a very large amount of measuring work needs yet to be accomplished before the exact values of the shifts of each line can be considered as definitely established.

The spectrograph employed for the work is designed to give the highest photographic resolution that can be obtained in the third order spectrum of either a Rowland or a Michelson grating. The former has 15,028 lines per inch over a ruled surface 3¼ in. long, and the latter has about 14,500 lines per inch and an effective ruling of 5 inches. The slit, collimator, and grating are mounted on a solid mass of masonry, the slit-mounting being firmly attached to a heavy iron rail which is embedded in cement. The camera-tube is

inclined to the collimator at an angle of 60 degrees, and the plate-holder is attached to a heavy mounting fixed on a separate masonry pier. The collimator lens is a visual achromatic of 7 ft. 6 in. focal length, and the camera lens is a single plano-convex of about 14 ft. focus for D. About bisecting the angle between camera and collimator is placed a 3-inch observing telescope, which receives light from the first or second order spectrum of the grating.

The slit is provided with various devices for simultaneous exposures on different light-sources and for alternate exposures. For the simultaneous exposures great attention is paid to the adjustment for securing a perfectly equal illumination of the grating from the different light sources to be compared. For the sun and arc comparisons photographs were obtained with a reflecting device placed in front of the slit, by means of which simultaneous exposures were obtained at the exact centre of the sun's disc and the arc spectrum of iron or other metal. The solar spectrum forms a central strip, 2 mm. in width, with the arc lines contiguous to it on each side. The illumination of the grating is adjusted with a wide slit, so that an image of the object glass or projecting lens may be seen on the grating by observing through the telescope with the eye-piece removed, and adjusted to coincidence for each source. The slit is then closed to its working width of ·03 to ·04 mm., the beam of light from each source is then spread laterally by diffraction and covers much more than the entire ruled surface of the grating. With this adjustment properly effected there can be no possibility of spurious shifts of the lines, due to unequal illumination of the grating from the two sources.

The arc was obtained with a direct current and with iron poles burning in air at a pressure of 580 mm., the normal pressure of the air at the elevation of the observatory. The current strength was between 5 and 10 amperes, and the length of the arc varied from about 5 to 10 mm. The poles were usually reversed during the middle of the exposure so as to equalise the intensity of the iron lines above and below the solar spectrum. Owing to the unequal relative intensities in different spectral regions of the sun and arc spectra, it was found necessary in photographing some of the less refrangible lines to give considerably longer exposures to the arc than to the sun, in order to get good measurable lines in both spectra, but in the more refrangible regions the exposures were usually synchronous, although in the H and K region where the arc lines are very intense the reverse procedure might be adopted with advantage.

The plates were measured in the direct and reversed position on the micrometer, and the mean of the observed shifts taken. Owing to a systematic bias in measuring the lines of bright and dark line contiguous spectra the shifts appear considerably larger in one position than in the other but this error is eliminated in the means. In a few cases the measures were made by the positive on negative method described in Kodaikanal Bulletin No. 32. A large number of the plates were measured in duplicate by different measurers and the mean results taken. In this work I have been greatly assisted by Miss Feline and Mr. Narayana Ayyar, B.A., third Assistant at this observatory.

The scale of the plates varies; it is about 1·2 mm. to the angstrom near K, and 1·8 mm. to the angstrom near D. A few fourth order plates have been measured in which the scale was 2·6 mm. to the angstrom.

The measures are difficult, and in some cases rather unsatisfactory. As the largest shifts found do not exceed 0·03 mm. in linear measure, and the limits of perception in the micrometer microscope for ordinary observers may be put at about 1/10 of this, it is obvious that the tabulated results must be subject to considerable errors, even when the mean is taken of several determinations. Nevertheless it is claimed that the order of magnitude of the different shifts is very fairly reliable, and cannot, I believe, be subject to changes which would modify the conclusions which I have based on them. Specially difficult lines such as those which are close doubles in the sun, or unsymmetrically widened, as well as lines which are very weak in the arc, are probably greatly affected by the personal habit of the measurer.

Some of the lines show a decided instability of position, giving sometimes a + and sometimes a — shift. This is not due to difficulty of measurement, since the lines are well defined in both sun and arc. I cannot say whether this instability is in the solar or arc lines, but in most cases where it occurs the plates have been re-measured and the results confirmed.

Another difficulty encountered is the systematic variation of the shifts from plate to plate. Although individual lines generally give the same relative shift on different plates, the absolute shift varies somewhat from plate to plate, so that measures from a single plate can only be trusted to give relative shifts.

As relative shifts however are of great importance in determining the relation to pressure shifts, I include in this discussion a number of lines for which only single plates have been available.

The actual measured shifts between solar and arc lines are of course affected by the earth's movements relative to the sun and in the reductions the component of the diurnal movement has been computed from the usual formula $V = \cdot 464 \sin t. \cos \delta. \cos \phi$, t being the hour angle of the sun, δ its declination and ϕ the latitude of Kodaikanal. The velocity at the earth's equator, ·464 Km/sec. is derived from Clarke's value of the equatorial semi-diameter. The orbital movement is taken out directly from the Nautical Almanac values of the radius-vector of the earth, no computation being required for the lunar perturbation since this is included in the velocities so obtained.

In table I, I give the residual shifts of the solar iron lines after eliminating the shifts due to the earth's movements. These are given in the fourth column. The fifth column gives the pressure shifts at nine atmospheres, taken from the tables of Gale and Adams * and supplemented by the measures of Humphreys and Duffield reduced to the same pressure. The unit in each of these columns is 0·001A. A sixth column is added for remarks. In the first two columns the wave-lengths and intensities are from Rowland, and the third column gives the number of plates measured from which the average shifts have been determined.

TABLE I.

λ Rowland.	Intensity.	Number of Plates.	Residual shift ⊙ − arc.	Pressure shift, 9 atmospheres.	Remarks.
3895·803	7	1	+ 14	+ 11	
3899·850	7	4	+ 19	+ 12	
3903·090	10	4	+ 17	+ 22	
3906·628	10	4	+ 11	+ 11	
3920·410	10	4	+ 15	+ 10	
3923·054	12	4	+ 14	+ 11	
3928·075	8	4	+ 18	+ 12	
3930·450	8	4	+ 14	+ 13	
3931·269	1	1	+ 8	...	
3935·965	2	1	+ 13	...	
3948·925	4	1	+ 6	+ 11	
3956·819	6	4	+ 4	+ 14	
3969·413	10	4	+ 14	+ 22	
3977·891	6	3	+ 6	+ 17	
3986·321	3	1	+ 5	+ 13	
3998·205	4	1	± 0	+ 14	
4005·408	7	3	+ 8	+ 19	
4009·864	3	1	− 5	+ 8	
4014·677	5	1	− 7	+ 11	
4022·018	5	1	± 0	+ 8	
4045·975	30	1	+ 4	+ 22	
4063·759	20	1	+ 2	+ 22	
4071·908	15	1	+ 5	+ 21	
4132·235	10	2	+ 20	+ 22	
4144·038	15	2	+ 14	+ 20	
4181·919	5	2	+ 3	+ 22	
4187·204	6	2	+ 7	+ 111	
4187·943	5	2	+ 8	+ 108	
4191·595	6	1	− 1	+ 110	
4199·267	5	2	+ 10	+ 32	
4202·198	8	2	+ 17	+ 15	
4219·516	7	2	+ 15	+ 26	Appears to be a single line in ⊙ and arc of intensity 7.
4227·606	4	2	− 1	+ 95	
4233·772	6	2	− 6	+ 90	
4236·112	8	2	+ 4	+ 90	
4250·287	8	1	+ 3	+ 70	
4260·640	10	1	+ 7	+ 51	
4271·325	6	1	+ 4	+ 123	
4271·934	15	1	+ 9	+ 22	
4282·565	5	1	+ 1	+ 21	
4308·081	6	2	+ 7	+ 21	
4315·262	4	2	+ 5?	+ 19	The plates give very inconsistent values.
4325·939	8	2	+ 11	+ 20	
4337·216	5	1	+ 6	+ 27	
4352·908	4	1	+ 5	+ 17	
4369·941	4	1	+ 11	+ 23	
4376·107	6	1	+ 14	+ 18	
4383·720	15	2	+ 11	+ 27	
4404·927	16	2	+ 9	+ 21	
4415·293	8	2	+ 12	+ 18	
4427·482	5	1	+ 3	+ 17	
4430·785	3	1	+ 2	+ 48	
4442·510	6	1	+ 9	+ 53	
4443·365	3	1	+ 5	+ 19	
4447·892	6	1	+ 14	+ 51	
4454·552	3	1	+ 8	+ 23	
4461·818	4	1	+ 8	+ 15	
4466·727	5	2	+ 17	+ 18	
4494·738	6	2	+ 12	+ 53	
4528·798	8	2	+ 11	+ 61	
4531·327	5	1	+ 4	+ 29	
4548·024	3	2	+ 6	+ 21	
4592·840	4	2	+ 8	+ 24	
4603·126	6	2	+ 8	+ 20	
4607·831	4	1	+ 2	...	
4619·468	3	1	+ 5	...	
4625·227	5	1	− 1	...	
4637·685	5	1	+ 1	...	
4638·193	4	1	+ 1	...	
4647·617	4	2	+ 10	+ 15	
4654·672	4	1	+ 3	...	
4654·800	5	1	+ 1	...	
4667·626	4	1	− 1	...	
4679·027	6	1	+ 2	...	
4707·457	5	1	+ 5	..	
4710·471	3	1	+ 4	+ 13	
4707·457	5	1	± 0	...	
4710·471	3	1	± 0	...	
4733·779	4	1	+ 1	...	
4736·963	6	1	+ 1	+ 18	
4787·003	2	1	+ 4	+ 16	

* Astrophysical Journal XXXV, 17.

TABLE I—*continued.*

λ Rowland.	Intensity.	Number of Plates.	Residual shift ⊙ − arc.	Pressure shift, 9 atmospheres.	Remarks.
4789·849	3	1	+ 6	+ 17	
4859·928	4	3	+ 2?	+ 100	The plates do not give consistent values.
4871·512	5	3	+ 4?	+ 80	
4872·332	4	3	+ 3	+ 94	
4878·407	4	3	+ 4	+ 87	
4890·948	6	3	+ 8	+ 70	
4891·683	8	3	+ 10	+ 53	
4903·502	5	3	± 0	...	
4919·174	6	2	± 0	+ 72	
4920·685	10	2	+ 4?	+ 82	One plate gives + and the other a − shift.
4938·997	4	1	− 2	...	
4957·480	5	1	+ 5	+ 83	
4957·785	8	1	+ 11	+ 86	
4966·270	4	1	− 1	...	
5002·044	5	1	− 2	...	
5005·896	4	1	− 1	.	
5006·306	5	1	+ 3	..	
5050·008	6	3	+ 6	...	
5051·825	4	3	+ 10	...	
5068·944	5	2	− 3	...	
5083·518	4	2	+ 7	...	
5098·885	3	1	+ 8	...	
5107·619	4	2	+ 4	...	
5107·823	4	2	+ 4	...	
5139·427	4	6	− 3	...	One plate gives a + and the rest − shifts.
5139·644	4	6	± 0	...	
5167·678	5	4	+ 16	...	
5169·069	3	1	+ 11	...	
5171·778	6	4	+ 15	+ 16	

λ Rowland.	Intensity.	Number of Plates.	Residual shift ⊙ − arc.	Pressure shift, 9 atmospheres.	Remarks.
5191·629	4	4	− 1	..	
5192·523	5	4	+ 2	...	
5195·113	4	4	+ 6	+ 17	
5216·437	3	3	+ 6		
5227·362	5	3	+ 3?	+ 31	The plates are inconsistent.
5233·122	7	3	+ 7	+ 110	
5266·738	6	2	− 4	+ 130	
5269·723	8	2	+ 9	+ 27	
5281·971	5	2	− 3?	...	The plates do not agree well.
5283·802	6	2	− 1?	...	
5302·480	5	2	− 3	..	
5324·373	7	2	+ 8?	+ 120	The plates are inconsistent.
5328·236	8	2	+ 15	+ 29	The line is single in ⊙ and are not two lines as given in Rowland.
5328·696	4	2	+ 8	+ 26	
5340·121	6	2	− 6	+ 140	
5371·734	7	2	+ 13	+ 29	
5397·344	7	4	+ 12	+ 29	
5405·989	6	3	+ 9	+ 27	
5424·290	6	1	+ 30	...	Very hazy line in arc (not included in discussion).
5429·911	6	4	+ 6	+ 29	
5434·740	5	4	+ 8	+ 27	
5447·130	6	4	+ 5	+ 31	
5455·834	4	4	+ 10	+ 29	
5569·848	6	1	+ 5	+ 140	
5573·075	6	1	+ 7	+ 140	
5586·991	7	2	+ 4	+ 120	
5615·877	6	2	+ 9	+ 130	

TABLE II.

λ Rowland.	Sun − Arc $\frac{\lambda}{1000}$. Evershed.	Sun − Arc $\frac{\lambda}{1000}$. Fabry and Buisson.	Remarks.
4181·919	+ 3	+ 2	
4187·204	+ 7	− 3	
4202·198	+ 17	+ 18	
4227·606	− 1	− 29	
4233·772	− 6	− 8	
4236·112	+ 4	− 19	
4250·287	+ 3	− 14	
4271·325	+ 4	− 18	
4282·565	+ 1	+ 7	
4337·216	+ 6	+ 7	
4352·908	+ 5	+ 4	
4369·941	+ 11	+ 6	
4376·107	+ 14	+ 12	
4427·482	+ 3	+ 4	
4430·785	+ 2	+ 6	
4442·510	+ 9	+ 12	
4443·365	+ 5	+ 7	
4447·892	+ 14	+ 7	
4461·818	+ 8	+ 9	
4466·727	+ 17	+ 14	
4531·327	+ 4	+ 5	
4787·003	+ 4	+ 6	

λ Rowland.	Sun − Arc $\frac{\lambda}{1000}$. Evershed.	Sun − Arc $\frac{\lambda}{1000}$. Fabry and Buisson.	Remarks.
4789·849	+ 6	+ 8	
4859·928	+ 2?	− 7	In some plates the shift is + and in others −.
4871·512	+ 4?	− 15	
4919·174	± 0	− 8	
5171·778	+ 15	+ 25	
5266·738	− 4	± 0	
5269·723	+ 9	+ 8	
5281·971	− 3	− 8	
5283·802	− 1?	+ 5	Measures not accordant.
5302·480	− 3	− 6	
5324·373	+ 8?	± 0	Measures not accordant.
5340·121	− 6	− 11	
5397·344	+ 12	+ 13	
5405·989	+ 9	+ 15	
5424·290	+ 30	+ 30	Arc line hazy.
5434·740	+ 8	+ 7	
5586·991	+ 4	+ 3	

In table II, I give a comparison of my results with the measures of MM. Fabry and Buisson,* who used the interference method in determining the displacements sun—arc. The two series are in fairly good agreement for most of the lines, but my measures differ from those of Fabry and Buisson chiefly in the case of the lines to which they assign large negative shifts. In six of these lines I get much smaller negative shifts, and in the remaining six small positive shifts. I do not think this difference can be due to errors of measurement, but is more probably the result of differences in the condition of the arc itself. MM. Fabry and Buisson refer to these lines as those which enlarge unsymmetrically towards the red in passing from the arc in vacuum to the arc in air, or on increasing the strength of the current in the arc. But in all my high dispersion plates taken with the arc at 110 volts and a current strength of about 6 amperes, the arc lines are very narrow and sharply bounded on both sides with no trace of any unsymmetrical widening, either towards the red or towards the violet; the only exceptions being lines which are reversed, and in these the settings were made on the exceedingly narrow reversal, which is sometimes unsymmetrically placed on the emission line.

In most cases the arc lines or their reversals are narrower than the solar lines, and it is difficult to believe that they do not represent the true centres of the lines, unaffected by unsymmetrical widening. This unsymmetrical widening appears to have caused a shift towards the red of the lines which in MM. Fabry and Buisson's measures give large negative sun—arc shifts. Possibly the sharp definition of the lines in my spectra may be due in part to the low atmospheric pressure of Kodaikanal, and in part to the fact that I used only the central portion of a comparatively long arc.

A glance at the fourth and fifth columns in table I is sufficient to show that no general relation exists between the solar and pressure shifts. The largest sun—arc shifts occur mostly in the ultra-violet region, whilst the pressure shifts increase enormously towards the red end of the spectrum.

If the shifts of the individual lines in the same spectral region are compared no marked relation can be made out, but differences of effective level may mask the relationship, those lines which are produced at greater depths in the reversing layer giving larger shifts owing to the greater pressure, and not necessarily because they are lines greatly affected by pressure.

But in order to justify the assumption that pressure is the cause of the solar shifts, an independent criterion of level must be sought, so that it may be determined whether an approximate agreement results between pressure shifts and solar shifts after making allowance for differences of level.

Although an exact correspondence between the relative shifts of individual lines is not to be expected, an approximate relation should be shown in the average shifts of groups of lines which are more and less affected by pressure; and low level lines should in general give larger shifts than high level. A general agreement in the law of increase of shifts with wave-length should also be found when groups of lines in different spectral regions are averaged. Thus, according to Duffield, the pressure shift is proportional to λ^2 or λ^3, and the solar shifts if due to pressure should increase similarly if the effects of differences of level can be eliminated.

In his research on radial motion in sunspots Dr. St. John has discovered a criterion of level in the intensity of the solar lines. It is clear, from my own observations and those of St. John, that the radial movement of the highest levels in the chromosphere is inward towards a spot centre, but the velocity of inrush decreases downwards to zero in a neutral zone at about the upper limits of the reversing layer. Below this, inversion occurs, the motion being outwards and necessarily increasing with the depth. In this region therefore the lines giving highest velocities in sunspots are due to absorption at the lowest levels, and St. John has deduced a scale of levels corresponding in a remarkable way with the scale of intensities of the lines, the weak lines indicating low levels, and the strong lines high levels. This result may be applied to the sun—arc shifts.

Owing to the comparatively small number of lines available it will be sufficient for the purpose of this inquiry to divide the lines in table I into three groups representing different spectral regions, each group containing the same number of lines with known pressure shifts. Group I contains a total of 35 lines

* Astrophysical Journal XXXI, 109.

between the limits λ 3895 and λ 4236; group II includes 46 lines between λ 4250 and λ 4787; and group III, 55 lines between λ 4789 and λ 5615.

If we subdivide these groups into high level and low level lines, according to intensity, we get the following interesting results :—

		Mean shift, sun—arc. A
Group I (Mean λ 4040) ...	Eighteen high level lines, Mean intensity, 11·2 ...	+ ·0125
	Seventeen low level lines, Mean intensity, 4·5 ...	+ ·0029
Group II (Mean λ 4500) ...	Seventeen high level lines, Mean intensity, 8·0 ...	+ ·0085
	Twenty-nine low level lines, Mean intensity, 4·0 ...	+ ·0043
Group III (Mean λ 5170)...	Twenty-three high level lines, Mean intensity, 6·8 ...	+ ·0066
	Thirty-two low level lines, Mean intensity, 4·2 ...	+ ·0039

There is here shown to be a very marked relation between the shifts and the intensities of the solar lines, the strong or high level lines giving in each group a much larger shift than the weak or low level lines, and the greater the difference of intensity (or level) the greater the difference of shift.

This is, of course, contrary to what would be expected if the solar shifts are due to pressure, for the low level lines represent higher pressures and therefore should show a larger shift than the high level lines.

If next we consider only the lines with known pressure shifts in the same three groups and separate them into those more and less affected by pressure, we get the following mean shifts sun—arc :—

	More affected.	Less affected.
Group I	+ ·0077A	+ ·0082A
Group II	+ ·0073A	+ ·0076A
Group III	+ ·0045A	+ ·0096A

In all the groups the less affected lines are slightly more shifted than the more affected. The grouping of the lines into those more or less affected by pressure is to some extent arbitrary, but owing to the very large differences of shift for different lines with no intermediate values, little or no ambiguity is involved. In the more affected lines I include those of Duffield's groups II and III, and in the less affected lines those of his group I.* Many more lines outside the range for his measures are however included, the pressure shifts being taken from the tables of Gale and Adams and of Humphreys.

The average pressure shift for the more and less affected lines in the three groups is as follows :—

	Mean λ.	More affected.	Less affected.
Group I	4050	·0076A per atmosphere.	·0017A per atmosphere.
Group II	4440	·0067A ,,	·0022A ,,
Group III	5170	·0102A ,,	·0026A ,,

Had the arc been under the normal pressure of 760 mm. in my experiments instead of about three-fourths of this value, or 580 mm., we may assume that all the arc lines would have been proportionately displaced towards the red, and the sun—arc shifts would have been reduced by about ¼ of the values given above. But since the more affected lines are shifted by amounts three to four times greater than the less affected, there will be a relative shift at the two pressures of approximately ·0015 A for groups I and II, and ·002 A for group III.

* Phil. Trans. A. 208, 160.

A correction should therefore be applied to the sun—arc shifts to reduce them to normal pressure, and the mean shifts already given would be modified as follows:—

	More affected.		Less affected.	
Group I	+ ·0077 − ·0019	= + ·0058	+ ·0082 − ·0004	= + ·0078
Group II	+ ·0073 − ·0017	= + ·0056	+ ·0076 − ·0005	= + ·0071
Group III	+ ·0045 − ·0025	= + ·0020	+ ·0096 − ·0007	= + ·0089

This corrected result shows that in all the three groups the lines less affected by pressure give quite appreciably larger displacements to the red than do the lines more affected by pressure; in other words, the most affected lines are relatively slightly displaced towards the violet in the sun, a result which confirms the conclusion I had previously arrived at in Bulletin No. XVIII, namely, that the pressure in the reversing layer is less than that in the arc at normal pressure.

MM. Fabry and Buisson however, in discussing the results of their measures, consider that the lines more affected by pressure, such as those of Duffield's group III, are unsuitable for estimating pressure in the sun, because they are the lines which widen unsymmetrically towards the red. In measuring the emission lines of the arc under pressure, a spurious displacement would be obtained, due to the unsymmetrical widening, and not to pressure. No indication is therefore given of the shifts of the absorption lines or reversals which alone would be applicable to the sun.

This appears to be partly true, for Duffield finds that when under pressure the emission line is unsymmetrically reversed, the absorption line is less shifted towards the red than the centre of the emission line, so that lines of his group III would then show only half the shift, and fall into group II. It is not at all clear, however, why the unsymmetrical widening which seems to cause excessive shifts to some of the emission lines in the arc under pressure should not also affect in a similar manner the solar absorption lines; for these do not represent a superficial layer of relatively low density, as do the reversals of the arc lines, but probably the entire mass of luminous gas above the photosphere. To make the arc under pressure strictly comparable with the sun, it would need to be observed with a background of continuous spectrum due to matter at a higher temperature than the luminous gas, and under these conditions the absorption lines would be the exact counterpart of the emission, and would show the combined shifts due to pressure and unsymmetrical widening.

However this may be, a comparison of the mean values of the shifts of Duffield's groups I and III, when reversals only are measured, shows a large difference of shift between the two groups. Granting therefore that the determinations of pressure shift of these more affected lines are to subject to considerable uncertainty, there can be no doubt as to their being much more shifted even as absorption lines than the less affected lines; and we may compare them in the sun with the less affected lines in order to discover whether the pressure in the reversing layer exceeds or falls short of one atmosphere.

MM. Fabry and Buisson proceed to estimate the pressure in the sun from the absolute shifts of the lines least affected by pressure. They get accordant values (5·5 atmospheres total pressure) from two sets of lines, namely, twenty lines between λλ 4000 and 4500 and ten lines between λλ 5100 and 5500. For the former the average shift sun—arc is + ·0062A and the latter + ·0103A.

Apart from the fact that the more affected lines are here ignored, for as I believe, a quite insufficient reason, no account is taken of differences of level in the effective regions of absorption of the different lines.

MM. Fabry and Buisson in measuring lines of only moderate intensity in the sun missed what appears to me to be a most significant fact, namely, the relation between shift and intensity. This was however recognized by Jewell,* who remarks that "the stronger reversed lines are those whose displacement is greatest (with reference to the solar lines), and there is gradual decrease in the amount of displacement as the lines are weaker and more difficult to reverse."

As regards the actual pressure indicated by the relative shifts of the more and less affected lines, the results of the three groups are not very consistent, except in so far as they indicate a pressure lower

* Astrophysical Journal III, 94.

than one atmosphere. The shifts of groups I and II would indicate a pressure only slightly less than that of the atmosphere at Kodaikanal, whilst group III would show an almost zero pressure.

If we suppose the solar gases to be under a pressure of five or six atmospheres, as MM. Fabry and Buisson's results appear to indicate, there can scarcely be a doubt that the lines most affected by pressure would in the sun show larger shifts than those less affected, even allowing that the pressure shifts of the more affected lines have been over-estimated.

The mean pressure shifts of the particular lines I have compared with the sun increase very greatly towards the longer wave-lengths, as is seen in the table of pressure shifts per atmosphere. For the more affected lines the shift is much larger for group III at mean λ 5200 than for group I at mean λ 4050. But for these same lines the sun—arc shifts actually diminish from +·0058A in group I to +·0020A in group III. Pressure therefore cannot be concerned with the shift to the red of these lines, and the smaller shifts of the less refrangible lines is only another instance of the relative displacement towards the violet of the lines most affected by pressure.

My conclusion therefore is that while pressure is not the cause of the shift of the solar lines to the red, there is in fact a small pressure effect traceable in the relative positions of the solar and arc lines, which is a *minus* effect, that is, indicating a decidedly smaller pressure in the sun than in the arc in air.

Assuming the pressure effect to be very small when comparing the arc at 580 mm. with the sun, we have now to account for the absolute shifts of the solar lines, most of which show a comparatively large displacement towards the red. I have already shown that these shifts are closely related to the intensities, the strong lines showing larger shifts than the weak. If we consider the shift to be due to motion in the line of sight, and also accept St. John's conclusions from movements in spots that the stronger lines represent in general higher levels and the weaker lines lower levels, we arrive at the interesting result that in the higher levels there is a movement of descent which is retarded in the lower levels.

For a comparison of the velocities deduced we are not limited to lines with known pressure shifts. Taking therefore all the lines I have measured, and separating them into strong and weak lines as before the following velocities are obtained:—

		Strong Lines. (Intensity 6 and over.)		*Weak Lines.* (Intensity 3 to 5.)	
Group.	Mean λ	Mean shift.	Km/sec.	Mean shift.	Km/sec.
I	4040	·0125A	·93	·0029A	·22
II	4500	·0085A	·57	·0043A	·29
III	5170	·0066A	·38	·0039A	·23

The movement is one of recession from the earth or descent on the sun in all cases, and the smaller velocity for the weaker lines is here clearly shown. The reduction of velocity for the strong lines in passing from group I to group III is readily explained, since the mean intensities decrease from 11·2 for group I to 8·0 for group II, and 6·8 for group III. For the weak lines the mean intensities are 4·5, 4·0, and 4·2, respectively.

The retardation of velocity in the lower region of the reversing layer satisfactorily explains the otherwise anomalous result that the shift, considered as a motion shift, does not increase towards the longer wave-lengths proportionately to λ but on the other hand tends to diminish. Considered as a pressure shift, this fact is quite inexplicable, for not only should the shift increase in proportion to λ^2 or λ^3 but it should, as already stated, be greater for the low-level lines than for the high level.

St. John has found that in general the lines at the red end of the spectrum represent lower levels than those at the violet end. This again tells against the pressure theory for it implies that the shifts if due to pressure should increase towards the red at an even greater rate than the pressure shifts.

Considering the pressure in the reversing layer to be less than one atmosphere, and the only possible explanation of the shifts of the solar lines to be motion in the line of sight, we leave unexplained the remarkable fact discovered by Halm of the relative shift to the red of the lines at the sun's limb compared with the centre of the disk. I propose to deal with this in a subsequent paper and will not say more here than that the usual interpretation of this shift based on differences of pressure of several atmospheres in the reversing layer appears from my results to be almost certainly erroneous.

The movement of descent of the iron vapour as observed at the centre of the disk seems to confirm the hypothesis I advanced in discussing the eclipse spectra photographed in 1900 namely that the cooler absorbing gases of the reversing layer are descending on the sun.* In this paper however I assumed a continuous *circulation* of the solar gases to account for the differences of intensity between the flash spectrum lines as observed at eclipses and the Fraunhofer lines; the hotter gases giving the enhanced lines rising, and the cooler gases falling. It seems probable that the descending motion of the iron vapour may turn out to be part of this circulating movement, but evidence of the ascending motion is still to be sought. It would be of much interest to compare the strongly enhanced spark lines of iron with the solar lines such as those at λλ 4924, 5018, 5169, and 5317 which might be expected to show an ascending movement, or a shift towards violet compared with the iron spark spectrum.

I have pleasure in acknowledging the assistance rendered me during this research by Dr. Royds, Assistant Director at this Observatory, whose management of the electrical appliances has been invaluable.

* Phil. Trans. A. 201, 477.

KODAIKANAL,
10th December 1913.

J. EVERSHED,
Director, Kodaikanal and Madras Observatories.

CORRECTION TO BULLETIN No. XXXVII.

The following paragraphs should be substituted for those at the bottom of page 56 under the heading "displacements of hydrogen lines":—

Displacements of hydrogen lines.

Attention has again been devoted to the displacements of the C line in prominences. Altogether 73 prominences showing displacements were observed; 34, or nearly half of them, were observed in high latitudes from 60° to the poles, 23 in latitudes from 30° to 60° and 16 between the equator and latitude 30°.

The largest displacement recorded was observed on September 27th at latitude + 69° and was estimated to be 5Å to the red. In the majority of cases the displacement was but slight.

The displacement was towards the violet in 38 cases, to the red in 31, and both ways simultaneously in 4. Forty were on the east limb and thirty-three on the west; forty-one were north of the equator and 32 south.

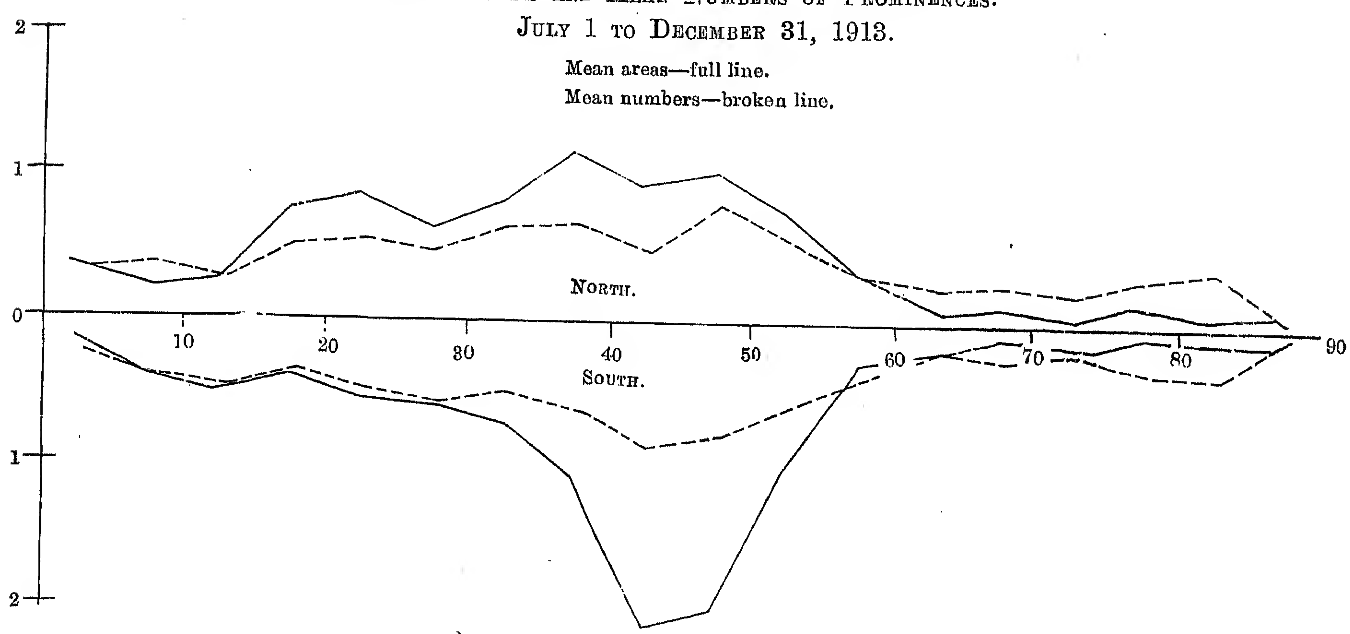
Kodaikanal Observatory.

BULLETIN No. XXXVII.

SUMMARY OF PROMINENCE OBSERVATIONS FOR THE SECOND HALF OF THE YEAR 1913.

The distribution in latitude of the prominences observed during the six months ending December 31, 1913, is represented in the accompanying diagram. The full line gives the mean daily areas, and the broken lines the mean daily numbers for each zone of 5° of latitude. The ordinates represent tenths of square minutes of arc for the full line and numbers for the broken line. The means are corrected for partial or imperfect observations, the total of 147 days being reduced to 126½ effective days.

MEAN AREAS AND MEAN NUMBERS OF PROMINENCES.
JULY 1 TO DECEMBER 31, 1913.



The mean daily areas and daily numbers for each hemisphere, corrected for partial observations are as follows:—

	Mean daily areas (square minutes).	Mean daily numbers.
North	0·91	7·61
South	1·01	7·15
Total ...	1·92	14·76

There is a reduction of area and of numbers in both hemispheres compared with the previous six months. The daily area has however increased in the region — 40° to — 50°, this being practically the only region of activity in the southern hemisphere. North of the equator the daily area in the belt + 40° to + 50° is on the other hand considerably reduced. Although the amounts of reduction of area and of numbers are sensibly equal, it is noteworthy that the southern hemisphere has been the more active hemisphere according to areas, but the less active according to numbers. This indicates that the average area of each prominence was greater in the southern hemisphere than in the northern.

The monthly, quarterly, and half-yearly frequencies, and the mean height and extent are given in the following table. The daily frequencies given are corrected for partial observations.

Abstract for the second half of 1913.

Months.	Number of days of observation.		Number of prominences.	Mean daily frequency.	Mean height.	Mean extent.
	Total.	Effective.				
					″	°
July	23	17½	313	17·9	28·8	1·01
August	27	22½	366	16·3	26·6	0·96
September	29	25½	361	14·2	26·4	1·24
October	24	21½	246	11·4	28·8	1·33
November	20	17½	300	17·1	27·4	1·02
December	24	22	287	13·0	28·9	1·32
Third quarter	79	65½	1,040	15·9	27·0	1·07
Fourth quarter... ...	68	61	833	13·7	28·3	1·21
Second half-year ...	147	126½	1,878	14·8	27·6	1·13

The reduction in the mean frequency compared with the previous six months has already been commented on above; there is a reduction in mean height, whilst the mean extent has remained practically the same.

The total number of prominences which attained heights of 60″ or over during the 147 days is 111 or an average of 1·3 per diem, as against 2·0 per diem during the previous six months. A prominence observed on November 14th at —42° west reaching a height of 240″, and one on December 20th at —32° west reaching 180″, were the highest prominences during the half-year.

Distribution east and west of the sun's axis.

The eastern limb again shows a preponderance over the western, but the preponderance is slight in the case of numbers. The data are as follows:—

1913—July to December—

	East.	West.	Percentage east.
Numbers observed	944	929	50·40
Total areas in square minutes of arc	127·1	116·5	52·18

Metallic prominences.

No prominences showing metallic lines were observed during the six months under consideration.

Displacements of the hydrogen lines.

Attention has again been devoted to the displacements of the C line in prominences. Altogether 39 prominences showing displacements were observed; 17, or nearly half of them, were observed in high latitudes from 60° to the poles, 14 in latitudes from 30° to 60° and 8 between the equator and latitude 30°.

The largest displacement recorded was observed on September 27th at latitude + 69° and was estimated to be 5 Å to the red. In the majority of cases the displacement was but slight.

The displacement was towards the violet in 20 cases, to the red in 15, and both ways simultaneously in 4. Eighteen were on the east limb and twenty on the west; twenty-four were north of the equator and fifteen south.

Reversals of the hydrogen lines on the disc.

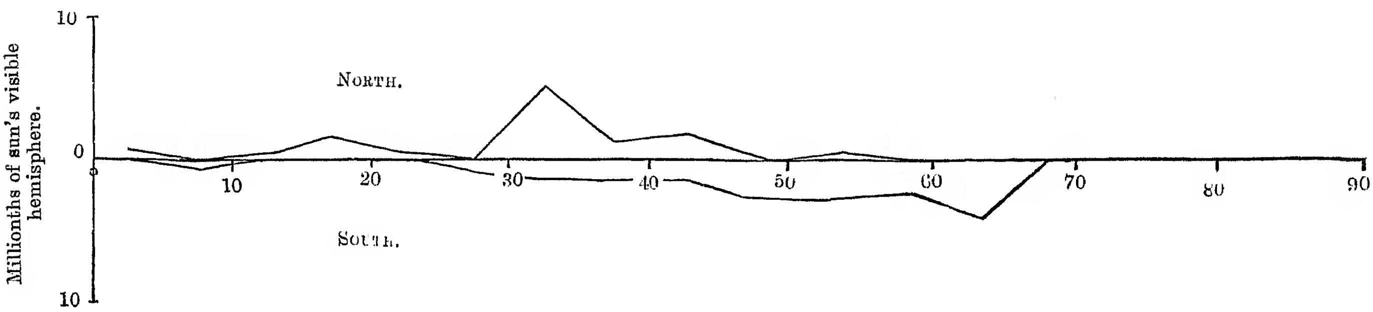
Reversals of the C line were recorded on four occasions in the neighbourhood of sunspots.

Prominences projected on the disc as absorption markings.

The sun's disc was photographed in Hα light on 71 days and on 30 of these days absorption markings are shown. Photographs were not taken after November 19th, as the grating was required for the spectrograph. The distribution of the markings in latitude are given in the accompanying diagram in which the mean daily areas, corrected for foreshortening, are given for each zone of 5° of latitude. The areas are expressed in millionths of the sun's visible hemisphere.

MEAN AREAS OF Hα ABSORPTION MARKINGS.
JULY 1 TO DECEMBER 31, 1913.

Total mean area for north hemisphere = 23·8 millionths.
Do. do. south do. = 36·3 do.



In the northern hemisphere, the distribution generally speaking follows that of prominences shown in Fig. 1, but the zone of greatest prominence activity between 35° and 55° in the southern hemisphere is not reproduced in the Hα absorption markings. South of the equator the area of the markings for each belt of 5° increases gradually up to the belt 60°—65° falling off to zero for latitudes higher than 70°.

The mean daily areas and daily numbers are given in the table below and compared with the previous six months :—

	1913—July to November.		1913—January to June.	
	Areas.	Numbers.	Areas.	Numbers.
North	24	0·28	44	0·24
South	36	0·30	84	0·56
Total ...	60	0·58	128	0·80

There is again a large reduction both in areas and numbers to record. The mean areas are reduced by 53·1 per cent. and numbers by 27·5 per cent.

THE OBSERVATORY, KODAIKANAL,
28*th February* 1914.

T. ROYDS,
Offg. Director, Kodaikanal and Madras Observatories.

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Kodaikanal Observatory.

BULLETIN No. XXXVIII.

A PRELIMINARY NOTE ON THE DISPLACEMENT TO THE VIOLET OF SOME LINES IN THE SOLAR SPECTRUM,

By T. Royds, D.Sc.

The majority of the metallic lines in the solar spectrum are shifted to the red when compared with their positions in the electric arc. There are, however, many exceptions. In the tables at the end of this paper I give the results of some comparisons of arc spectra (chiefly iron) with the spectrum of the centre of the sun's disc for the study of these exceptions.

I. IRON LINES.

1. Sun and Arc Comparisons.

The iron spectrum was produced by the arc between iron terminals in air at 580 mm. pressure (the normal pressure at the altitude of the Observatory) with a direct current from a battery at 110 volts. The current strength was usually between 6 and 8 amperes, and the length of the arc was varied in different experiments. The polarity of the terminals was reversed at the middle of the exposure in order to equalise the intensity of the arc lines above and below the solar spectrum. The same arrangement as was previously used [1] for simultaneous exposure on the sun and arc was employed but the duration of exposure on the arc was varied in different regions in order to produce lines easily measurable. The spectrograph has been previously described [2].

It was at once noticed that nearly all lines which are unsharp in the arc at ordinary pressures gave negative values for the sun—arc displacement, *i.e.*, were relatively shifted towards the violet in the sun (*e.g.*, λ 3948·246, Table VIII), but that several lines apparently sharp (*e.g.*, λ 4233·772, Table VIII) were also shifted to the violet. On considering, however, the behaviour of these lines under pressure, it was found that the lines shifted to the violet, including those apparently sharp, were those which widen unsymmetrically towards the red with increased pressure, and which therefore are really unsymmetrical at atmospheric pressure, but not obviously so. The number of lines shifted to the violet was apparently greater on photographs taken using an extremely short arc (about 2 mms. in length), as was done in some regions between λ 4924 and λ 5317 in order to obtain the enhanced lines as strong as possible. These plates were therefore considered first, and the lines sorted out according to the Mount Wilson classification of the iron lines [3]. The Mount Wilson workers have divided the iron lines into groups *a*, *b*, *c*, *sub-d*, *d*, or *e* according to their pressure shifts, and also into classes 1, 2, 3, 4, 5, or 6; lines of classes 1, 2, 3, and 4 remain symmetrical under pressure, class 5 widen unsymmetrically towards the red and class 6 unsymmetrically towards the violet. When the sun—short arc displacements (Table VIII) are grouped according to the character of the arc lines, as in Table I below, it is seen that whilst symmetrical lines (groups *a* and *b*) have normal displacements to the red in the sun, unsymmetrical lines (groups *c*5, *d*, *sub-d*, and *e*) behave abnormally; lines widened unsymmetrically in the arc towards the red are displaced to the violet of the arc line, and the line 5133, much widened towards the violet, is greatly displaced to the red [4]. The lines in group *c* which have not been classified are, judged from their negative displacements, probably widened unsymmetrically towards the red.

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[1] Evershed and Royds, Roy. Astr. Soc., M. N., 73, 554, 1913. [2] Evershed, Kodaikanal Observatory Bulletin No. XXXVI

[3] { Gale and Adams, Astrophysical Journal, 35, 10, 1912, St. John and Miss Ware, Astrophysical Journal, 36, 14, 1912 and 39, 5, 1913.

[4] The line 5424 measured by Evershed and by Fabry and Buisson to have a displacement in the sun of + ·030 Å is also widened to the violet.

TABLE I.—SUN—SHORT ARC DISPLACEMENTS.

A.—Symmetrical Lines.

λ				Group.	Sun—Short Arc in Å/1000.
4376·107	...	...	...	*a* 3	+ 6
4427·482	...	...	...	*a* 3	+ 0
4994·316	...	...	...	*a*	+ 5
5028·308	...	...	...	*a*	+ 3
5151·020	...	...	...	*a*	+ 7
5195·113	...	...	...	*a*	− 1
5216·437	..	..	...	*a*	+ 1
5242·658	...	...	...	*a*	+ 5
4337·216	...	...	...	*b* 3	+ 9
4352·908	...	...	...	*b* 3	+ 3
4383·720		...	...	*b* 1	+ 9
4404·927	...	...	...	*b* 1	+ 5
		Mean displacement	...		+ ·0043 Å

B.—Lines unsymmetrically widened towards the red.

λ				Group.	Sun—Short Arc in Å/1000.
4210·494	...	...	...	*c* 5	0
4890·948	...	...	...	*c* 5	− 2
4919·174	...	...	...	*c* 5	− 12
4957·480	...	...	...	*c* 5	− 6
4966·270	...	...	...	*c* 5	− 8
4233·772	...	...	...	*d* 5	− 13
4982·682	...	...	...	*d* 5	− 18
5192·523	...	...	...	*sub-d*	− 11
5208·776	...	...		*sub-d*	− 3
5215·353	...	...	...	*sub-d*	− 14
5263·486	...	...	...	*sub-d*	− 4
5273·339	...	...	...	*sub-d*	− 12
5281·971	...	...	...	*sub-d*	− 9
5302·480	...	...	...	*sub-d*	− 8
		Mean displacement	...		− ·0086 Å

C.—Lines unsymmetrically widened towards the violet.

λ				Group.	Sun—Short Arc in Å/1000.
4191·843 *	...	...	...	*e*	0
5133 870	...	...	...	*e*	+ 35

D.—Lines of group c unclassified.

λ				Group.	Sun—Short Arc in Å/1000.
4938·997	...	...	...	*c*	− 10
66·270	...	...	...	*c*	− 11
85·432	...	...	...	*c*	− 8
85·730	...	...	...	*c*	− 6
5005·896	...	...		*c*	− 8
06·306	...	...	...	*c*	− 7
15·123	...	...	...	*c*	− 3
22·414	...	...	...	*c*	− 6
5139·427	...	...	...	*c*	− 11
39·644	...	...	...	*c*	− 11
91·629	...	...	...	*c*	− 14
5217·552	...	...	...	*c*	− 8
		Mean displacement ...			− ·0086 Å

* The 4191·8 line is not nearly so unsymmetrical as the 5133 line.

The relative shifts of these different groups are very striking. They cannot be easily explained as shifts due to a difference of pressure between the sun and arc for on this assumption the deduced solar pressure has the impossible value of about one atmosphere *below vacuum;* moreover we shall see later that a relative displacement of these groups can be produced by different conditions of the arc at the same pressure. In fact, the abnormal shifts seem to depend solely on the unsymmetrical character of the lines. Nevertheless they are not wholly due to errors of setting on an unsymmetrical line. It is true that in the case of a line widened unsymmetrically towards the red, for example, the tendency would be to set too far on the red side of the true maximum and the solar line would appear to be displaced too much towards the violet, but there are many lines displaced to the violet in which the error of setting must be extremely small, for they are very narrow. There are also many lines particularly of other elements than iron, *e.g.*, the sodium pair λλ 6161, 6154 and the calcium triplet λλ 6162, 6122, 6102, all on the same plate, where a glance at the photographs shows that the shift is real. It is possible also that the lines unsymmetrical in the arc are unsymmetrical in the sun as well, but there is at present no evidence of such being the case. The error introduced through setting on the centre of a solar line really unsymmetrical would, however, have the effect of making the true shifts still more abnormal, and therefore need not now be considered.

The above results were obtained in comparing the sun with a short arc. Most of my photographs using a long arc were taken in the ultraviolet and blue regions and there are not many lines belonging to the unsymmetrical classes, but the following are measurable in both sun and arc:—

TABLE II.—SUN—LONG ARC DISPLACEMENTS.

Lines unsymmetrically widened towards the Red.

λ	Group.	Sun—Long arc in Å/1000
4227·606	*d* 5	— 5
33·772	*d* 5	— 6
36·112	*d* 5	+ 3
50·287	*c* 5	+ 7

Mr. Evershed[1], using a long arc, has many lines of groups *d* 5, *sub-d* and *c* in his list; 12 are shifted to the violet in the sun and 21 to the red. It is clear that with the long arc displacements to the violet are less frequent than when the sun and short arc are compared. None of the lines known to be symmetrical are shifted to the violet of the long arc according to the measures either of Fabry and Buisson[2], Evershed[1] or myself.

There are in addition to the lines already discussed many iron lines which have not been classified according to their character and pressure displacement. Many such lines are unsharp in the arc at atmospheric pressure and when the sun is compared with the short arc none of these lines are displaced to the red. With the long arc, however, 10 are displaced to the violet and 10 to the red, 4 being undisplaced. It is not possible to say from the photographs at atmospheric pressure alone whether these unsharp lines are unsymmetrical or not.

2. COMPARISON OF THE LONG ARC AND SHORT ARC.

The fact of negative values for the sun—arc displacement being more frequent with the short arc than with the long suggested the possibility of certain classes of lines being displaced in the short arc. I made some comparisons of the sun and an arc 2 mms. long, and of the sun and an arc 7 mms. long, keeping the current as nearly as possible the same, thus obtaining indirectly the displacement between the short and long arcs. Also, three photographs were taken directly confronting the central portions of the long and short arcs on the same plate. The results are given in Table VIII at the end. It is hoped to make a more complete investigation shortly, but there is a clear indication of the different behaviour of unsymmetrical lines. Those lines unsymmetrically widened towards the red are shifted in the short arc to the red, those widened towards the violet are shifted to the violet, whilst symmetrical lines have smaller displacements as a rule, if they are really displaced at all.[3] The average displacements, short arc—long arc, for the different groups are given in the following table:—

[1] Evershed, Kodaikanal Observatory Bulletin, No. XXXVI. [2] Fabry and Buisson, Astrophysical Journal, 31, 109, 1910.

[Note added May 5th.—Photographs recently obtained of other unsymmetrical lines not only confirm these conclusions but also, by having the lines equally wide in both the long and short arcs, show that the shifts are not due to errors of setting on the maxima of unsymmetrical lines].

TABLE III.—SHORT ARC—LONG ARC DISPLACEMENTS.

	Symmetrical Lines.			Lines unsymmetrical towards the red.			Lines unsymmetrical towards the violet.
Group	*a*	*b*	*c* 4	*c* 5 and *c*	*sub-d*	*d*	*e*
Average Displacement in Å ...	+ ·0007	− ·0001	+ ·004	+ ·0076	+ ·0067	+ ·0135	− ·0085
Number of Lines	10	7	1	5	3	2	2
Means	+ ·0006 Å			+ ·0085 Å			− ·0085 Å

The following are some of largest displacements measured as yet :—

TABLE IV.—LARGE VALUES FOR SHORT ARC—LONG ARC DISPLACEMENT.

λ		Short arc—Long arc in Å/1000.
4157·948	... ...	+ 11
4158·959	... ...	+ 6
4233·772	... ...	+ 7
5133·870	... ...	− 15
5162·449	... ...	+ 20

Now St. John and Miss Ware[1] found different wavelengths for the lines in one arc photograph compared with four others taken under apparently the same conditions. Moreover the displacement between this photograph and the rest varied according to the class of line. They give the following means for three groups of lines :—

Group	*b*	*d*	*e*
Average displacement	—·0006 Å	+·012 Å	—·007 Å.
Number of lines	5	4	5

These displacements are exactly similar to the displacements I have found in the short arc, and since the arc spectrum appeared stronger in the displaced photograph than in the rest it seems likely that the arc was in this case shorter, or possibly had a greater current density. St. John and Miss Ware state that pressure variations within the arc are not of sufficient magnitude to account for the shifts measured. They also state that the displacement occurs in the region of the arc near the negative pole, where the lines are strongest and most widened. In my photographs any dissimilarity between the two poles is lost owing to the practice of reversing the polarity in the middle of the exposure, and I have therefore not been able to test this latter conclusion.[2]

It is noteworthy that of the seven lines for which Mr. Evershed did not get consistent values for the sun—arc displacement when more than one photograph was available, all except two are unsymmetrical lines. The different values are therefore probably due to different lengths of the arc. Also the discrepancies between Evershed's values and those of Fabry and Buisson[1] can now be explained. Their values agree extremely well for all symmetrical lines, whilst for all the lines widened unsymmetrically towards the red in the arc Fabry and Buisson find the solar lines to be much more shifted to the violet relative to their arc. This is shown clearly by the following averages for the symmetrical and the unsymmetrical lines in Evershed's Table II :—

Lines symmetrical in the arc (Groups *a*, *b*, *c*4).		Lines unsymmetrically widened towards the red in the arc (Groups c5, *sub-d*, *d*).	
Sun—Arc displacement.		*Sun—Arc displacement.*	
Evershed.	Fabry and Buisson.	Evershed.	Fabry and Buisson.
+ ·0082 Å	+ ·0088 Å	— ·0001 Å	— ·0089 Å

[1] Evershed, Kodaikanal Observatory Bulletin, No. XXXVI.

[2] [Note added May 5th :—I have now been able to confirm this statement of St. John and Miss Ware].

According to my results, MM. Fabry and Buisson's larger shift to the violet of the unsymmetrical can be explained if they have had a shorter arc than Mr. Evershed, or, it may be, had a greater density of material in the arc.

3. A new cause of the displacement of lines.

There is now therefore a considerable amount of evidence of the displacements of certain classes of iron lines due to some other cause than pressure or motion in the line of sight. The most obvious cause which suggests itself is change of density since this is the principal change which occurs in varying the length of the arc. The density hypothesis is strongly supported by a phenomenon observed by Duffield[1] the significance of which has not been sufficiently appreciated, namely, that in all the reversed lines which were unsymmetrically widened towards the red under pressure, the emission line was displaced to the red of the absorption line. The emission line is due to the inner portions of the arc where the density is high and the line broad, and the absorption line is due to the outer portions where the density is low and the line narrow. This is in agreement with the displacement between the short arc and the long, for the lines unsymmetrically widened towards the red are shifted to the red by shortening the arc, which corresponds to increasing the density. King[2] has tried the effect on wavelength of varying the density of the iron vapour in the furnace with negative results, but unfortunately all the lines tested belong to group *a*, which I also find to have very small displacements.

Since the unsymmetrical lines are displaced in the short arc in the opposite direction to their displacement in the sun when both are compared with the long arc, it follows that the condition of the vapour, whether it is density or not, in the long arc more nearly approaches that in the reversing layer than the condition in the short arc. But still the long arc falls short of the conditions in the reversing layer of the sun, since many unsymmetrical lines are still abnormally displaced. For this reason and especially because it is desirable to have the density of the vapour under control, it is intended to try the furnace spectrum for comparison with the sun.

The existence of a density effect on wavelength may modify some of the conclusions which have been drawn from the displacement between solar and terrestrial sources. For instance, if the pressure in the reversing layer is deduced by comparing the displacements of the lines most shifted to the red by pressure with those least shifted, we must now bear in mind that the former consist chiefly of lines which are displaced by density whilst the latter are not. The relative displacement of the former to the violet would lead to the conclusion that the pressure in the sun is less than atmospheric, but it now appears that it is due, to some extent at least, to the different conditions in the sun and arc, probably difference of density. For the present, therefore, we are compelled to confine our attention to the symmetrical lines since, so far as we know, they are affected least, if at all, by the peculiar conditions in the arc. Firstly we can compare the shifts of the lines of groups *a*, *b*, *c*2 and *c*4, all symmetrical, in the same spectral region, and secondly, since there happen to be lines of group *a*, both in the ultraviolet and in the yellow-green regions, we can compare the shifts in these two regions knowing the law according to which the pressure shift varies with wavelength. Making use also of Evershed's values I obtain the following average sun—long arc displacements for each group of iron lines.

TABLE V.

	Mean wavelength, λ 4400.			Mean wavelength, λ 3800.		Mean wavelength, λ 5250.
	Group *a*.	Group *b*.	Groups *c*2 and *c*4.	Group *a*.	Group *b*.	Group *a*.
Pressure shift at 9 atmospheres.	+ ·0158 Å.	+ ·023 Å.	+ ·0547 Å.	+ ·0105 Å.	+ ·0164 Å.	+ ·029 Å.
Mean sun—long arc displacement.	+ ·0072 Å.	+ ·0090 Å.	+ ·0090 Å.	+ ·0076 Å.	+ ·0075 Å.	+ ·0088 Å.
Mean intensity ...	4	7	6·5	13	13	5
Number of lines ...	4	15	6	14	13	19

[1] Duffield. Phil. Trans. Roy. Soc. A., 208, 111, 1908. [2] King. Astrophysical Journal, 35, 183, 191.

7. The unsymmetrical iron lines are therefore, owing to their behaviour in the arc, unsuitable for estimating the pressure in the reversing layer. Using symmetrical lines only, the deduced pressure in the sun is about equal to that of the air at the altitude of the Observatory, *i.e.*, about three-quarters of an atmosphere.

8. The displacements of the symmetrical iron lines to the red in the sun are due to descending motion on the sun as discovered by Evershed.

9. Lines of other elements than iron also have sun—arc displacements which cannot be explained as due to pressure or to motion in the line of sight.

I have much pleasure in acknowledging my indebtedness to Messrs. G. Nagaraja Ayyar and A. A. Narayana Ayyar, B.A., for the careful and painstaking manner in which they have measured the photographs for this Bulletin.

Explanation of Table VIII.

Table VIII contains all the iron lines on the displacements of which the conclusions arrived at in this Bulletin are based. The photographs were taken with the same spectrographic arrangements as those used by Mr. Evershed, but the values here given are, apart from this fact, independent of those in Bulletin XXXVI.

The wavelengths and intensities in columns 1 and 2 are taken from Rowland's tables; a letter *n* in the second column denotes that the line appears unsharp in the arc at atmospheric pressure. The third column gives the Mount Wilson classification of the iron lines. The remaining columns contain the measured displacements, sun—long arc, sun—short arc and short arc—long arc, respectively, and the number of photographs measured.

TABLE VIII.

λ	Intensity.	Group.	Number of plates.	Sun-long arc in Å/1000.	Number of plates.	Sun-short arc in Å/1000.	Number of plates.	Short arc—long arc in Å/1000	λ
3650·178	5*n*	...	2	+ 6	...	...	...	...	3650·178
80·069	9	*a*l	2	+ 10	...	...	...	...	80·069
97·567	5*n*	...	2	— 16	...	..	...	...	97·567
3701·234	8*n*	...	2	+ 5	...	..	...	...	3701·234
05·708	9	*a*l	2	0	...	...	...	...	05·708
07·186	5*n*	...	2	— 1	...	...	...	...	07·186
09·389	8	*b*l	2	— 2	...	...	...	...	09·389
16·591	7	...	2	— 5	...	...	...	...	16·591
20·084	40	*a*l	2	+ 10	...	...	...	...	20·084
24·526	6	...	2	+ 3	...	...	...	...	24·526
27·244	3	...	2	— 2	...	...	...	...	27·244
35·014	40	*b*l	2	+ 9	...	...	...	..	35·014
37·281	30	*a*l	2	+ 1	...	...	...	...	37·281
48·408	10	*a*l	2	+ 2	...	...	...	...	48·408
49·631	20	*b*l	2	+ 2	...	...	...	...	49·631
60·196	5	...	2	— 1	...	...	...	...	60·196
60·679	4	...	2	0	...	...	...	...	60·679
63·945	10	*b*l	2	+ 7	...	...	...	...	63·945
67·341	8	*b*l	2	+ 3	...	...	...	...	67·341
3815·987	15	*b*l	2	+ 18	...	...	...	...	3815·987
26·027	20	*b*l	2	+ 6	...	...	...	...	26·027
27·980	8	*b*l	2	+ 6	...	...	...	...	27·980
43·404	4	...	2	+ 4	...	...	...	...	43·404
46·943	5	...	2	+ 2	...	...	...	...	46·943
50·118	10	...	2	— 2	...	...	...	...	50·118
50·962	4	...	2	+ 3	...	...	...	...	50·962
52·714	4	...	2	— 1	...	...	...	...	52·714
56·524	8	...	2	+ 7	...	...	..	...	56·524
59·355	3	...	2	+ 11	...	...	...	...	59·355
60·055	20	...	2	+ 11	...	...	...	...	60·055
85·657	4	...	4	+ 5	...	...	...	...	85·657
86·434	15	*a*l	4	+ 4	...	...	...	...	86·434
87·196	7	*b*l	4	+ 8	...	...	...	...	87·196
90·980	3*n*	...	4	+ 6	...	...	...	...	90·980
92·069	4	...	2	+ 3	...	...	...	...	92·069
94·057	2	...	2	— 1	...	...	...	...	94·057
97·596	2	...	2	+ 4	...	...	...	...	97·596
3906·628	10	*a*l	2	+ 4	...	...	...	...	3906·628
08·077	5	...	2	+ 2	...	...	...	...	08·077
13·775	4	...	2	+ 1	...	...	...	...	13·775
16·879	5	...	2	0	...	...	...	...	16·879
20·410	10	*a*l	2	+ 11	...	...	...	...	20·410
23·054	12*d* ?	*a*l	2	+ 5	...	...	...	...	23·054

TABLE VIII—*cont.*

λ	Intensity.	Group.	Number of plates.	Sun-long arc in Å/1000.	Number of plates.	Sun-short arc in Å/1000.	Number of plates.	Short arc—long arc in Å/1000.	λ
3925·790	5	...	2	+ 3	...	...	...	...	3925·790
28·075	8	a1	2	+ 11	...	...	...	...	28·075
30·450	8	a1	2	+ 5	...	...	...	...	30·450
32·785	1n	...	2	+ 5	...	...	...	...	32·785
37·479	3	...	2	0	...	...	...	...	27·479
48·246	5n	...	2	— 11	...	...	...	...	48·246
50·102	5	...	2	+ 4	...	...	...	...	50·102
56·819	6	b4	2	+ 3	...	...	...	...	56·819
63·252	3n		2	— 6	...	...	...	...	63·252
66·212	3	...	2	+ 2	...	...	...	...	66·212
66·778	3n	..	2	+ 10	...	...	...	...	66·778
4022·018	5	...	1	— 2	...	...	...	...	4022·018
24·881	4n		1	— 4	...	...	...	...	24·881
40·792	3	...	2	+ 1	...	...	...	...	40·792
45·975	30	b1	3	+ 9	...	+ 9[1]	1	0	45·975
62·599	5	...	2	+ 4	...	...	.	...	62·599
63·759	20	b1	3	+ 7	...	+ 8[1]	1	— 1	63·759
66·742	2	...	1	— 1	...	...	1	0	66·742
67·139	5	.	2	+ 10	...	...	1	+ 1	67·139
67·429	3	...	2	+ 3	...	...	1	+ 1	67·429
68·14	...	...	...	...	...	...	1	0	68·14
70·930	4n	...	1	0	...	...	1	— 1	70·930
71·908	15	b1	4	+ 10	...	+ 11[1]	1	— 1	71·908
73·921	4n	...	1	0	...		1	+ 4	73·921
74·947	3	...	1	+ 3	...	...	1	+ 1	74·947
76·792	4n	...	1	0	...		1	+ 4	76·792
79·996	3	...	2	+ 1	...	...	...	...	79·996
84·647	5n	...	1	+ 3	...	...	1	+ 3	84·647
85·161	4	...	2	+ 4	...	...	1	0	85·161
85·467	4	...	...	...	...	...	1	— 1	85·467
96·129	3	...	1	+ 2	...	...	1	— 1	96·129
98·335	5n	...	1	— 1	...	...	1	0	98·335
4100·901	4	...	2	+ 5	...	...	1	0	4100·901
14·606	4	...	2	+ 4	...	...	...	...	14·606
18·708	5	...	3	+ 5	...	...	...	...	18·708
22·673	3	...	2	+ 1	...	...	...	...	22·673
27·767	4	...	2	+ 2	...	...	...	...	27·767
32·235	10	b1	3	+ 13	...	...	...	...	32·235
33·062	4	...	1	+ 9	...	...	...	...	33·062
34·840	5	b4	3	+ 2	...	...	...	...	34·840
44·038	15	b1	3	+ 11	...	...	...	...	44·038
54·667	4	...	1	+ 7	1	+ 6	...	+ 1[1]	54·667
54·976	4	5[2]	1	— 2	1	— 3	...	+ 1[1]	54·976
56·970	3	...	1	+ 4	1	+ 7	...	— 3[1]	56·970
57·948	5	...	1	— 10	1	— 21	...	+ 11[1]	57·948
58·959	5	...	1	— 14	1	— 20	...	+ 6[1]	58·959
74·095	3	...	...	...	1	+ 2	...	...	74·095
75·806	5	...	4	+ 2	1	+ 3	...	— 1[1]	75·806
81·919	5	...	3	+ 6	...	...	...	...	81·919
87·204	6n	5[2]	6	+ 1	...	...	...	...	87·204
87·943	6	...	5	+ 8	...	...	...	...	87·943
91·595	6n	5[2]	6	+ 2	...	...	...	...	91·595
91·843	3n	e	1	— 2	1	0	...	— 2[1]	91·843
95·492	5	...	1	— 3	1	— 6	...	+ 3[1]	95·492
96·372	4	...	1	— 7	1	— 11	...	+ 4[1]	96·272
4200·148	2	...	...	...	1	+ 4	...	...	4200·148
02·198	8	b1	6	+ 10	...	...	...	...	02·198
10·494	4	c5	1	+ 3	1	0	...	+ 3[1]	10·494
13·812	3	...	1	— 2	1	+ 2	...	...	13·812
16·351	3d ?	b3	3	+ 3	...	...	...	...	16·351
22·382	5n	5[2]	4	— 2	1	— 6	1	+ 4[1]	22·382
25·619	3	...	1	+ 1	...	...	...	...	25·619
26·584	2	...	1	— 9	1	— 10	1	+ 1[1]	26·584
27·606	4	d5	1	— 5	...	...	...	...	27·606
29·677	2	...	...	...	1	+ 3	...	...	29·677
29·926	3	...	...	...	1	— 2	...	...	29·926
33·772	6	d5	4	— 6	1	— 13	1	+ 7[1]	33·772
36·112	8	d5	1	+ 3	...	...	...	...	36·112
38·970	5n	...	4	— 15	1	— 24	1	+ 7[1]	38·970
50·287	8	c5	2	+ 7	...	...	...	...	50·287
58·477	2	...	1	+ 9	...	...	...	...	58·477
67·122	3	...	1	+ 6	...	...	...	...	67·122
71·325	6	5[2]	2	+ 5	...	...	...	..	71·325
71·934	15	b1	5	+ 17	...	...	...	...	71·934
82·565	5	b1	2	+ 10	...	...	...	...	82·565
90·542	1	...	1	+ 4	...	...	...	...	90·542
4315·262	4	b3	2	+ 14	...	...	...	...	4315·262

[1] These values are obtained from the other two columns by subtraction. [2] According to Fabry and Buisson.

λ	Intensity.	Group.	Number of plates.	Sun-long arc in Å/1000.	Number of plates.	Sun-short arc in Å/1000.	Number of plates.	Short arc—long arc in Å/1000.	λ
4321·961	2	...	1	+ 7	...	...	...	...	4321·961
25·939	8	b1	5	+ 12	...	...	...	...	25·939
26·923	2	...	1	+ 4	...	...	...	...	26·923
28·080	2	...	1	+ 7	...	...	...	...	28·080
37·216	5	b3	2	+ 8	...	+ 9[1]	1	— 1	37·216
52·908	4	b3	2	+ 4	...	+ 3[1]	1	+ 1	52·908
68·071	2	...	...	...	.	...	1	+ 2	68·071
76·107	6	a3	1	+ 7	...	+ 6[1]	1	+ 1	76·107
83·720	15	b1	2	+ 8	...	+ 9[1]	1	— 1	83·720
88·571	3n	...	1	— 7	...	...	1	+ 4	88·571
4401·456	2	...	1	— 4	...	...	...	..	4401·456
04·927	10	b1	2	+ 7	...	+ 5[1]	1	+ 2	04·927
15·298	8	b1	2	+ 6	...	...	...	...	15·298
27·482	5	a3	2	+ 3	...	0[1]	1	+ 3	27·482
30·785	3n	c4	1	+ 1	...	...	1	+ 4	30·785
33·390	3n	...	1	+ 4	...	...	1	+ 4	33·390
35·321	2n	...	1	+ 5	...	...	1	+ 1	35·321
42·510	6	c4	2	+ 8	...	...	...	..	42·510
43·365	3	b3	1	+ 3	...	...	...	...	43·365
54·552	3	b3	1	+ 5	...	...	...	...	54·552
61·818	4	a3	2	+ 7	...	...	...	...	61·818
4525·314	5n	...	...	...	1	— 8	..	.	4525·314
28·798	8	...	...	...	1	+ 8	...	...	28·798
31·327	5	...	...	..	1	+ 6	...	...	31·327
48·024	3	...	...	..	1	— 4	...	...	48·024
92·840	4	...	...	...	1	+ 4	...	...	92·840
4603·126	8	...	...	...	1	+ 2	...	...	4603·126
4890·948	6	c5	...	...	2	— 2	...	...	4890·948
4919·174	...	c5	...	...	2	— 12	...	...	4919·174
24·107	p Fe 5	...	...	...	1	— 10	..	...	24·107
38·997	4	c	...	...	...	— 10	...	...	38·997
57·480	...	c5	..	...	...	— 6	...	...	57·480
66·270	4	c5	...	...	...	— 8	...	...	66·270
82·682	4n	d	...	...	2	— 18	...	...	82·682
83·433	3n	...	...	...	1	— 14	...	...	83·488
84·028	3n		...	...	2	+ 2	...	...	84·028
85·432	3	c	...	..	2	— 8	...	...	85·432
85·780	3	c	...	...	2	— 6	...	...	85·730
94·816	3	a	...	...	2	+ 5	...	...	94·316
5002·044	5	...	...	..	2	— 7	...	...	5002·044
05·896	4	c	...	...	2	— 8	...	...	05·896
06·306	5	c	...	...	2	— 7	...	...	06·306
15·123	3n	c	...	...	2	— 3	...	...	15·123
18·629	p Fe 4	...	...	...	2	+ 16	...	...	18·629
22·414	3	c	...		2	— 6	...	...	22·414
28·308	2	a	...	...	2	+ 3	...	...	28·308
5133·870	4n	e	...	...	1	+ 35	2	— 15	5133·870
39·427	4	c	...	...	1	— 11	2	+ 9	39·427
39·644	4	c	...	...	1	— 11	2	+ 9	39·644
48·111	3	...	...	...	1	+ 5	2	0	48·111
51·020	4	a	...	...	1	+ 7	2	0	51·020
62·449	5n	d	...	...	1	[3] large —	1	+ 20	62·449
69·069	3	...	...	...	1	+ 2	1	— 1	69·069
69·220	p Fe 4	...	...	...	1	+ 18	..	...	69·220
91·629	4	c	...	...	1	— 14	2	+ 9	91·629
92·523	5	sub-d	...	...	1	— 11	2	+ 10	92·523
95·113	3	a	...	..	1	— 1	2	0	95·113
5208·776	2n	sub-d	...	...	1	— 3	2	+ 4	5208·776
15·353	3n	sub-d	...	...	1	— 14	2	+ 6	15·353
16·437	3	c	...	...	1	+ 1	2	0	16·437
17·552	3n	a	...	...	1	— 8	2	+ 8	17·552
42·658	2	a	...	...	1	+ 5	...	...	42·658
50·817	2	...	..	...	1	+ 3	...	...	50·817
63·486	4n	sub-d	...	...	1	— 4	...	...	63·486
73·339	3n	sub-d	...	...	1	— 12	...	...	73·389
81·971	5	sub-d 5[2]	...	...	1	— 9	...	...	81·971
83·802	6	sub-d[4]	...	...	1	— 8	...	...	83·802
5302·480	5	sub-d 5[2]	...	...	1	— 9	...	...	5302·480
07·541	3	...	...	...	1	+ 3	...	...	07·541
16·790	p Fe 4	...	...	...	1	— 1	...	.	16·790
5123·899	8	a	...	...	...	...	1	+ 1	5123·899
5127·583	3	a	...	...	...	...	1	+ 2	5127·583
5162·087	3	a	...	...	...	...	1	— 1	5152·087
5167·678	5	a	...	...	...	...	1	+ 1	5167·678
5171·778	6	...	...	...	...	...	1	0	5171·778
5202·516	4	a	...	...	...	...	1	0	5202·516

[1] These values are obtained from the other two columns by subtraction.

[2] According to Fabry and Buisson.

[3] 33 with the long arc according to Evershed.

[4] Symmetrical according to Fabry and Buisson.

Table IX.

[The pressure shift is taken from Humphreys' tables. Those lines unsymmetrically widened to the red are marked ur.]

λ	Intensity.	Pressure shift in Å per atmosphere.	Number of plates.	Sun—arc in Å /1000.	λ	Intensity.	Pressure shift in Å per atmosphere.	Number of plates.	Sun – arc in Å /1000.
3949·039	Ca 1 ur	...	2	— 10	5682·869	Na 5 ur	·0532	1	–127
4095·094	Ca 4 ur	...	2	— 86	5688·436	Na 6 ur	·0575	1	–144
4098·689	Ca 4 ur	...	2	— 78	5890·186	Na 30	·0127	2	+ 8
4226·904	Ca 20	·0051	1	— 2	5896·155	Na 20	·0122	2	+ 7
4283·169	Ca 4	·0031	3	+ 6	6154·438	Na 2 ur	...	2	– 81
4302·692	Ca 4	·0031	3	+ 10	6160·956	Na 3 ur	...	2	– 79
4289·525	Ca 4	·0035	3	+ 10	4077·885	Sr 8	·0026	3	+ 14
4299·149	Ca 3	·0035	3	+ 6	4215·703	Sr 5 d ?	·0034	4	+ 15
4425·608	Ca 4	·0084	3	+ 2	4607·510	Sr 1	·0053	3	+ 1
4435 129	Ca 5	·0081	3	+ 3	4554·211	Ba 8 d	·0036	2	– 5
4438·851	Ca 4	...	3	+ 2	4934·24	Ba 7 d	·0038	2	– 12
4456·784	Ca 2	·0079	3	+ 7	4703·177	Mg 10 ur	...	1	– 37
4527·101	Ca 3 ur	...	1	— 44	5167·497	Mg 15 ur	·0083	3	– 10*
4578·732	Ca 3 ur	...	2	— 25	5172·856	Mg 20 ur	·0078	3	– 7*
4581·575	Ca 4 ur	...	2	— 24	5183·791	Mg 30 ur	·0059	3	– 9*
4586·047	Ca 4 ur	...	2	— 20	4680·317	Zn 1	0057	3	– 8
5262·419	Ca 3	...	1	0	4722·342	Zn 3	·0073	3	– 9
5264·415	Ca 3	...		+ 1	4810·724	Zn 3	·0065	2	– 14
5270·438	Ca 3	...	1	— 3	3944·169	Al 15	·0052	2	+ 3
5265·729	Ca 3	...	1	— 2	3961·674	Al 20	·0058	2	+ 2
5582·198	Ca 4	...	2	+ 2	4709·896	Mn 2	...	2	+ 3
5588·985	Ca 6	...	2	+ 2	4739·291	Mn 3	...	2	– 1
5590·843	Ca 3	...	2	+ 1	4754·225	Mn 7 ur	...	4	– 6
5594·691	Ca 4	0072	2	+ 1	4783·613	Mn 6 ur	...	4	– 6
5601·505	Ca 3	...	2	+ 1	4823·697	Mn 5 ur	...	3	– 6
5698·711	Ca 4	...	2	+ 1	4761·718	Mn 3	...	3	– 2
6102·937	Ca 9	·0255	2	— 27	4762·567	Mn 5	...	3	– 2
6122·434	Ca 10	·0226	2	— 24	4766·050	Mn 3	...	3	0
6162·890	Ca 15	·0225	2	— 28	4766 621	Mn 4	...	3	– 3

* Calculated from limb displacements relative to centre of sun and to arc.

The Observatory, Kodaikanal,
18*th April* 1914.

T. ROYDS,
Assistant Director.

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Kodaikanal Observatory.

BULLETIN No. XXXIX.

ON THE DISPLACEMENTS OF THE SPECTRUM LINES AT THE SUN'S LIMB.

An investigation of the displacements of the spectrum lines at the sun's limb was made by W. S. Adams in 1909, using the tower telescope and 30-foot spectrograph at Mount Wilson.* It was shown that, if we except the lines characteristic of the higher chromosphere which show little or no displacement, the great majority of the lines are displaced to the red relatively to the lines at the centre of the disk. This relative shift increases with the wave-length for all the elements investigated, and for iron the displacements increase rather more rapidly than in direct proportion to wave-length.

Dr. Adams adopts the explanation of this shift suggested by Halm, who believed it to be due mainly to pressure, the effective region of absorption at the limb being supposed to be at a lower level and therefore higher pressure than at the centre of the disk, owing to the relatively longer path of tangential rays in the lower levels of the reversing layer compared with the rays passing normally through the solar atmosphere, as at the centre of the disk.

As an alternative to this theory we might suppose the shifts to be due to motion in the line of sight. If the gases are ascending radially all over the sun with the required velocity, the relative shift to the red at the limb as compared with the centre of the disk would result. This however is ruled out because we find a descending, not an ascending movement, when the positions of the lines at the centre are directly compared with those from a terrestrial source. If the shifts are the result of movement then they can be explained only by a motion parallel to the solar surface, and directed away from the earth at all points of the solar circumference. This suggests that the earth itself controls the movement, exerting a repelling action on the solar gases.

Obviously the pressure theory presents a much more rational explanation of the phenomenon than the motion theory; yet there are difficulties in accepting the former which have not been in any way lessened, but on the contrary have been largely increased, by further research. An initial difficulty which appeals to us is the absence of any evidence of shading or indefinite edges on the red sides of the lines near the sun's limb. If the photospheric light coming from the limb passes through successive layers of diminishing pressure, one would expect the absorption to begin gradually at the red edge of a line, especially as the absorption would be weakest in the lowest and hottest layers where the pressure is greatest, and would increase as the rays entered the cooler regions of less pressure. The red sides of the displaced lines should therefore appear indefinitely bounded, yet no trace of any such effect is apparent. The lines of the limb spectrum are broader than those of the centre spectrum, but they are sharply bounded on both red and violet edges. Perhaps the strongest argument in favour of the pressure theory which Adams gave in his paper is based on the relative shifts of the iron lines which are most and least affected by pressure. He found that the lines most affected by pressure gave the largest limb — centre shifts, and he also argued that the large increase of shift with wave-length for the iron lines pointed to pressure as the main factor in the case.

We find it difficult to accept these results, because we consider that the relative shifts of different lines at the limb have no particular meaning when determined by reference to the lines at the centre of the disk, for these latter have shifts peculiar to themselves, and our measures show that the absolute shifts of the lines

* Astrophysical Journal XXXI, 30, 1910.

at the limb referred to a terrestrial standard show no relation to pressure shifts, and further, the absolute shifts do not increase with the wave-length.

We have discussed in Kodaikanal Observatory Bulletin Nos. XXXVI and XXXVIII the shifts of the lines at the centre of the disk compared with the arc in air, and consider that our results clearly show that pressure is not concerned in the general displacement of the solar lines towards the red. A small pressure effect is nevertheless traceable, but this indicates a pressure of less than one atmosphere in the region of iron absorption as observed at the centre of the disk.

This result seems to argue against any large pressure effect at the limb, such as would be deduced from the shifts limb — centre.

Determination of limb shifts.

In determining the absolute shifts of the lines at the limb we have simply combined our measures of the limb — centre shifts with the centre — arc shifts, the algebraical sum of the shifts representing the absolute or limb — arc shifts. A number of direct measures of the limb — arc shifts were also made by one of us, and these, so far as they go, confirm the indirect determinations.

The spectrograph employed has already been described in Kodaikanal Observatory Bulletin No. XXXVI. For the limb — centre shifts photographs are obtained by means of a reflecting device placed in front of the spectrograph slit. With this apparatus simultaneous exposures are made with light from the centre of the disk and from points one-thirtieth of the sun's radius inside the limb at the opposite ends of a diameter. The spectra form three contiguous strips on the plate each about 1·5 mm. in width. After the exposure on the sun, an exposure is made on the iron arc to impress the iron lines on the plate outside the solar spectra: these serve to determine accurately the inclination of the micrometer thread to the spectrum lines in measuring the displacements, but are not used to determine centre — arc or limb — arc shifts on these plates. In this way the total shift west limb — east limb due to the solar rotation may be accurately determined as well as the limb — centre shifts.

In table I we give a list of all the iron lines of which we have measures of both limb — centre shifts and centre — arc shifts. The algebraical sum of these given in column 6 represents the absolute shift of the lines near the limb when compared with the iron arc in air at 580 mm. pressure, the normal pressure at Kodaikanal.

TABLE I.—SHIFTS OF IRON LINES.

λ (Rowland).	Intensity.	Limb — centre. Kodaikanal.	Limb — centre. Mt. Wilson.	⊙ — arc.	Sum.	Remarks.	Number of measures. Limb — centre.	Number of measures. ⊙ — arc.
		A/1000.	A/1000	A/1000.	A/1000			
3895·803	7	− 3	...	+ 14	+ 11		2	4
3899·850	7	− 4	...	+ 19	+ 15		4	4
3903·090	10	− 2	...	+ 17	+ 15		4	4
3906·628	10	+ 4	...	+ 11	+ 15		5	4
3920·410	10	− 1	+ 6	+ 15	+ 17	3 plates give zero shift and one plate — 6 (limb — centre).	4	4
3923·054	12	+ 7	...	+ 14	+ 21		4	4
3925·790	5	+ 7	...	+ 5	+ 12		3	1
3928·075	8	+ 2	...	+ 18	+ 20		2	4
3930·450	8	+ 2	...	+ 14	+ 16		5	4
3931·269	1	+ 8	...	+ 8	+ 16		3	1
3935·965	2	+ 4	...	+ 13	+ 17		3	1
3937·479	3	+ 3	...	0	+ 3		3	1
3948·925	4	+ 8	...	+ 6	+ 14		3	1
3950·102	5	+ 6	+ 6	+ 5	+ 11		4	1
3956·819	6	+ 6	+ 7	+ 4	+ 11		5	4
3966·212	3	+ 4	...	+ 4	+ 8		3	1
3969·413	10	+ 4	...	+ 14	+ 18		5	4
3977·891	6	+ 7	+ 6	+ 6	+ 13		6	3
3986·321	3	+ 6	...	+ 5	+ 11		2	1
3998·205	4	+ 7	...	0	+ 7		2	1
4005·408	7	+ 8	+ 8	+ 8	+ 16		1	3
4009·864	3	+ 9	...	− 5	+ 4		1	1
4022·018	5	+ 14	+ 9	0	+ 12		1	1
4045·975	30	+ 8	...	+ 6	+ 14		1	2

TABLE I.—SHIFTS OF IRON LINES—*cont.*

λ (Rowland).	Intensity.	Limb − centre. Kodaikanal.	Limb − centre. Mt. Wilson.	⊙ — arc.	Sum.	Remarks.	Number of measures. Limb — centre.	Number of measures. ⊙ — arc.
		A/1000.	A/1000.	A/1000.	A/1000.			
4062·599	5	+ 8	...	+ 4	+ 12		1	2
4063·759	20	+ 8	+ 8	+ 6	+ 14		1	4
4071·908	15	+ 3	...	+ 8	+ 11		1	3
4076·792	4	+ 7	...	+ 3	+ 10		1	1
4118·708	5	+ 6	...	+ 3	+ 9		3	2
4127·767	4	+ 5	...	+ 5	+ 10		2	2
4134·840	5	+ 6	...	+ 2	+ 8		2	2
4140·089	6	− 1	..	(+ 12)	+ 11	Limb — arc direct measure.	2	...
4144·038	15	...	+ 8	+ 14	+ 22		..	3
4147·836	4	+ 7	...	(+ 2)	+ 9	Limb — arc direct measure.	3	...
4154·667	4	+ 6	...	+ 7	+ 13		3	2
4175·806	5	+ 6	...	+ 2	+ 8		3	4
4181·919	5	+ 7	...	+ 4	+ 11		1	6
4187·204	6	+ 2	...	+ 7	+ 9	Unsharp line in arc	2	3
4191·595	6	+ 3	...	+ 2	+ 5		3	6
4202·198	8	+ 3	+ 5	+ 11	+ 15		4	4
4220·509	3	+ 7	+ 8	(0)	+ 8	Limb — arc direct measure.	1	...
4227·606	4	+ 4	...	+ 5	+ 9		1	2
4233·772	6	+ 7	+ 8	— 1	+ 7		1	3
4236·112	8	− 7	...	+ 4	− 3		1	3
4250·287	8	− 3	...	+ 6	+ 3		3	2
4260·640	10	+ 7	+ 4	+ 7	+ 12		2	1
4271·325	6	+ 3	...	+ 5	+ 8		3	3
4271·934	15	− 6	+ 6	+ 9	+ 9		2	3
4282·565	5	+ 7	+ 7	+ 7	+ 14		2	4
4308·081	6	+ 10	...	+ 8	+ 18		4	4
4315·262	4	+ 9	+ 8	+ 9	+ 18		7	4
4325·939	8	+ 2	+ 3	+ 10	+ 13		6	6
4337·216	5	+ 8	+ 8	+ 5	+ 13		6	4
4352·908	4	+ 6	+ 6	+ 4	+ 10		7	3
4369·941	4	+ 12	...	+ 11	+ 23		2	1
4376·107	6	+ 4	+ 5	+ 11	+ 15		2	2
4383·720	15	+ 1	...	+ 9	+ 10		2	5
4404·927	10	− 1	...	+ 9	+ 8		3	4
4415·293	8	+ 3	...	+ 12	+ 15		4	2
4427·482	5	+ 10	...	+ 3	+ 13		3	4
4430·785	3	+ 8	+ 8	+ 1	+ 9		4	3
4442·510	6	+ 4	+ 6	+ 8	+ 13		3	3
4443·865	3	+ 11	+ 7	+ 4	+ 13		2	2
4447·892	6	+ 4	+ 5	+ 14	+ 18		1	1
4454·552	3	+ 7	+ 7	+ 6	+ 13		2	2
4461·818	4	+ 7	+ 7	+ 7	+ 14		3	3
4466·727	5	+ 8	...	+ 12	+ 20		2	4
4494·738	6	+ 6	+ 10	+ 7	+ 15		3	4
4508·455	4	...	+ 11	+ 4	+ 15	p Fe in short arc	...	1
4515·508	3	...	+ 11	+ 3	+ 14	p Fe in short arc	...	1
4522·802	3	...	+ 10	− 2	+ 8	p Fe in short arc	...	1
4528·798	8	+ 4	+ 5	+ 10	+ 14		4	3
4531·327	5	+ 8	+ 7	+ 5	+ 12		5	2
4548·024	3	+ 4	+ 8	+ 6	+ 12		4	2
4549·642	2	...	+ 8	0	+ 8	p Fe in short arc	...	1
4556·063	3	...	+ 11	+ 1	+ 12	p Fe in short arc	...	1
4584·018	4	...	+ 12	+ 4	+ 16	p Fe in short arc	...	1
4592·840	4	+ 6	...	+ 8	+ 14		4	2
4603·126	6	+ 4	...	+ 8	+ 12		3	2
4607·831	4	+ 7	...	+ 2	+ 9		2	1
4619·468	3	+ 4	...	+ 5	+ 9		2	1
4625·227	5	+ 7	...	− 1	+ 6		2	1
4637·685	5	+ 4	...	+ 1	+ 5		2	1
4638·193	4	+ 5	...	+ 1	+ 6		2	1
4647·617	4	+ 7	...	+ 9	+ 16		1	2
4654·672	4	+ 6	...	+ 3	+ 9		1	1
4654·800	5	+ 9	...	+ 1	+ 10		1	1
4667·626	4	+ 6	...	− 1	+ 5		2	1
4679·027	6	+ 6	...	+ 2	+ 8		2	1
4707·457	5	+ 4	...	+ 5	+ 9		1	1
4733·779	4	...	+ 10	+ 1	+ 11		...	1
4736·963	6	...	+ 8	+ 1	+ 9		...	1
4787·003	2	...	+ 8	+ 4	+ 12		...	1
4789·849	3	...	+ 7	+ 6	+ 13		...	1
4859·928	4	...	+ 9	+ 2	+ 11		...	3

TABLE I.—SHIFTS OF IRON LINES—*cont.*

λ (Rowland).	Intensity.	Limb − centre. Kodaikanal.	Limb − centre. Mt. Wilson.	$\odot$ − arc.	Sum.	Remarks.	Number of measures. Limb−centre.	Number of measures. $\odot$ − arc.
		A/1000.	A/1000.	A/1000.	A/1000.			
4871·512	5	+ 8	+ 9	+ 4	+ 13		1	8
4872·832	4	+ 6	...	+ 2	+ 9		1	8
4890·948	6	+ 5	...	+ 8	+ 13		1	8
4891·683	8	− 1	...	+ 10	+ 9		1	8
4903·502	5	+ 17	...	0	+ 17		1	8
4919·174	6	...	+ 9	0	+ 9		...	2
4924·107	5	...	+ 9	+ 5	+ 14	p Fe in short arc	...	1
5018·629	4	...	+ 8	+ 16	+ 24	p Fe in short arc	...	2
5083·518	4	...	+ 9	+ 7	+ 16		...	2
5107·619	4	0	...	+ 4	+ 4		2	2
5107·828	4	+ 12	...	+ 4	+ 16		2	2
5139·427	4	+ 3	...	− 3	0	$\odot$ − short arc = − 11	2	4
5139·644	4	...	+ 7	0	+ 7		...	5
5162·449	5	+ 6	...	− 33	?	Faint and diffuse line in arc.	1	1
5167·678	5	+ 17	...	+ 16	+ 33	b_4.	1	4
5169·069	3	− 1	...	+ 11	+ 10		1	1
5169·220	4	+ 8	...	+ 18	+ 26	p Fe in short arc	1	1
5171·778	6	− 2	...	+ 15	+ 13		1	4
5191·629	4	+ 6	...	− 1	+ 5	$\odot$ − short arc = − 14	1	4
5192·523	5	0	...	+ 2	+ 2	$\odot$ − short arc = − 11	2	4
5195·113	4	+ 4	+ 8	+ 6	+ 12	$\odot$ − short arc = − 1	1	4
5216·437	3	+ 3	...	+ 6	+ 9	$\odot$ − short arc = + 1	2	8
5227·362	5	+ 3	...	+ 3	+ 6		1	3
5233·122	7	0	...	+ 7	+ 7		1	3
5266·738	6	+ 5	...	− 4	+ 1		1	2
5269·723	8	− 1	...	+ 9	+ 8		1	2
5281·971	5	+ 1	...	− 3	− 2	$\odot$ − short arc = − 9	1	2
5283·802	6	+ 4	...	− 1	+ 3	$\odot$ − short arc = − 7	1	2
5302·480	5	+ 3	...	− 3	0		2	2
5316·790	4	+ 9	+ 12	− 1	+ 10	p Fe in short arc	2	1
5324·373	7	+ 2	...	+ 9	+ 11		2	2
5328·236	8	+ 3	...	+ 15	+ 18		2	2
5328·721	4	+ 7	...	+ 8	+ 15		2	2
5340·121	6	+ 5	...	− 6	− 1		2	2
5405·989	6	...	+ 9	+ 9	+ 18		...	8
5424·290	6	...	+ 7	+ 30	+ 37	Faint and diffuse in arc	...	1
5429·911	6	...	+ 9	+ 6	+ 15		...	4
5434·740	5	...	+ 10	+ 8	+ 18		...	4
5447·130	6	...	+ 10	+ 5	+ 15		...	4
5455·834	4	...	+ 8	+ 19	+ 27		...	4
5509·848	6	+ 9	+ 11	+ 5	+ 16		4	1
5573·075	6	+ 5	...	+ 7	+ 12		4	1
5586·991	7	+ 5	+ 10	+ 4	+ 12		4	2
5615·877	6	+ 1	+ 9	+ 9	+ 14		4	...

In forming this table we have given Dr. Adams' values of the limb shifts in column 4 under the heading "Mount Wilson" and these values have been used in forming column 6 for the lines which we have not yet measured. For lines measured at both observatories the mean of the two determinations of limb — centre has been used. For most of the common lines the agreement between Mount Wilson and Kodaikanal is excellent, but there are two or three marked discrepancies such as the lines 3920·410 and 4271·934, which according to our measures are shifted towards the violet instead of towards the red as in Dr. Adams' determinations. The values in column 6 for these lines must be subject to considerable uncertainty.

As regards the relative accuracy of the different determinations, we give in the last two columns of table I the number of measures on which each value depends. In most cases several plates taken at different dates and in different solar latitudes have been used for each determination of limb — centre or sun — arc shift. There appear to be considerable systematic variations in the amount of the shifts given by different plates, for both limb — centre and centre — arc, so that values obtained from one plate only are subject to this variation from the mean in addition to the greater accidental error of measurement.

The sun — arc measures are the same as those given in Kodaikanal Observatory Bulletin No. XXXVI, with additions and improved values for many of the lines obtained from later measures.

Limb shifts in relation to the intensity of the lines.

The first point to be noted in these measures is the relation to intensity. If the lines are grouped according to their intensity in the sun the following mean results are obtained :—

TABLE II.—MEAN SHIFTS IN RELATION TO INTENSITY.

Intensity.	Number of lines.	Limb – centre.	Centre – arc.	Limb – arc.
8 and over	24	+ 0·0023 A	+ 0·0107 A	+ 0·0130 A
7 and 6	33	+ 0·0047	+ 0·0063	+ 0·0110
5	26	+ 0·0074	+ 0·0037	+ 0·0111
4	34	+ 0·0073	+ 0·0051	+ 0·0124
3 and under	20	+ 0·0066	+ 0·0038	+ 0·0104

In this table all the lines of table I are used in forming the means excepting two. These are the lines at λ 5162·449 and λ 5424·290, which give very anomalous shifts due to peculiar conditions in the arc. Many other lines also are probably affected by the arc conditions, especially those which widen unsymmetrically under pressure, but as it is not at present possible to classify all the lines of table I it has seemed best to take general means, excluding only those above-mentioned lines which give enormous centre — arc shifts which are almost certainly not connected with solar conditions.

Although individual lines for each intensity give very different shifts for both limb — centre and centre — arc, the relation to intensity is well marked in the means. The limb shifts increase as the intensity diminishes from the strongest lines to intensity 5, whilst the centre shifts decrease over the same range. Below intensity 5 the shifts are nearly constant. If the arc lines may be considered to be in their normal positions, then the relation to intensity of the limb — centre shifts is only an apparent one and is really due to the varying shifts of the lines at the centre of the disk, for the added shifts given in the last column "limb — arc" show practically no relation to intensity.

Relation between limb shifts and pressure shifts.

If we group the total shifts, limb — arc at 580 mm. pressure according to the amount of the pressure shifts, the following results are obtained :—

TABLE III.—MEAN SHIFTS IN RELATION TO PRESSURE SHIFTS.

Region.	Number of lines.	Mean pressure shift per atmosphere.	Mean shift limb — arc.
	A.—Lines most affected by pressure.		
4187–4528	13	+ 0·0097 A.	+ 0·0092 A.
4859–5615	14	+ 0·0134	+ 0·0096
	B.—Lines least affected by pressure.		
3895–4466	40	+ 0·0022	+ 0·0140
4531–5455	19	+ 0·0029	+ 0·0140

It is here seen that the mean limb shifts do not increase as do the pressure shifts in passing from the more refrangible to the less refrangible groups of lines, and that the lines most affected by pressure are least shifted at the limb.

If the limb — arc shifts are corrected for the defect of pressure at Kodaikanal from normal and the results for the two spectral regions are averaged, the limb — arc shifts for normal pressure become + 0·0065 A for the lines most affected by pressure, and + 0·0134 A for the lines least affected by pressure. If the wave-lengths of the arc lines are supposed to be unaffected by other conditions, this would mean a total pressure at the limb of 0·24 atmosphere only, but it is very questionable whether the arc under the conditions of our experiments does give "normal" wave-lengths for many of the lines. Dr. Royds has shown that lines which are unsymmetrical in the arc (*i.e.*, the majority of lines with large pressure shifts) are displaced in the short arc compared with the long arc.* This shift is not due to pressure differences or to motion, but appears to be a density effect, and there are reasons for believing that in the long arc (5 to 7mm.) the conditions, although approaching more nearly to solar conditions than in the short arc, are still far from being the same as in the reversing layer, where the gases appear to be of the last degree of tenuity. Many of the arc lines therefore which we have compared with the sun, and especially those which give abnormal pressure shifts, may be

* Kodaikanal Observatory Bulletin No. XXXVIII.

affected by this density shift which would in general tend to reduce the sun — arc shifts for the lines most affected by pressure.

It would seem probable therefore that this density shift may partly account for the low values obtained for the lines most affected by pressure. Even if we concede that the whole difference of shift between the lines most and least affected by pressure (which would amount to about 0·007 A when the arc is at normal pressure) is due to the density effect, the figures would imply an absolute pressure near the limb of one atmosphere only, and the difference of pressure between limb and centre of disk about one-fourth of an atmosphere.

It is probable that a better knowledge of the effect of pressure at the limb may be gained by a comparison of the shifts of only those lines which widen symmetrically in the arc under pressure. In our list there are only 45 lines which are known to be of this character, and the pressure shifts of these lines do not vary very widely: they may nevertheless be separated into two groups comprising the more and the less affected lines.

In table IV the shifts of the symmetrical lines are set out in detail with the mean values in Angstrom units at the foot of each column. The pressure shifts in column 2 are from the tables of Gale and Adams.*

TABLE IV.—MEAN SHIFTS OF SYMMETRICAL LINES IN RELATION TO PRESSURE SHIFTS.

λ	Pressure shift. 8 Atmospheres.	Limb shift.	Centre shift.	Total shift.
	A.—Lines most affected by pressure.			
3903·090	+ 22	− 2	+ 17	+ 15
3969·413	22	+ 4	14	18
4045·975	23	8	6	14
4134·840	27	6	2	8
4144·038	29	8	14	22
4202·198	25	4	11	15
4271·934	22	0	9	9
4337·216	27	8	5	13
4369·941	23	12	11	23
4383·720	27	1	9	10
4454·552	23	7	6	13
4581·327	29	7	5	12
5227·362	31	3	3	6
5269·723	27	− 1	9	8
5328·236	29	+ 3	15	18
5328·721	26	7	8	15
5405·989	27	9	9	18
5429·911	29	9	6	15
5434·740	27	10	8	18
5447·130	31	10	5	15
5455·834	29	8	19	27
Means ...	+ ·0264	+ ·0058	+ ·0091	+ ·0149
	B.—Lines least affected by pressure.			
3895·803	+ 11	− 3	+ 14	+ 11
3899·850	12	− 4	19	15
3906·628	11	+ 4	11	15
3920·410	10	2	15	17
3923·054	11	7	14	21
3928·075	12	2	18	20
3930·450	13	2	14	16
3956·819	14	7	4	11
3977·891	17	7	6	13
4005·408	19	8	8	16
4063·759	20	8	6	14
4071·908	21	3	8	11
4282·565	21	7	7	14
4308·081	21	10	8	18
4315·262	19	9	9	18
4325·939	20	3	10	13
4352·908	17	6	4	10
4376·107	18	4	11	15
4404·927	21	− 1	9	8
4415·293	18	+ 3	12	15
4427·482	17	10	3	13
4443·365	19	9	4	13
4461·818	15	7	7	14
4466·727	18	8	12	20
Means ...	+ ·0164	+ ·0049	+ ·0097	+ ·0146

* Astrophysical Journal XXXV, 8, 1912.

The mean total shift limb — arc is practically identical for the two sets of lines, although the mean pressure shifts are in the ratio 1 : 1·6. This would of course imply that the total pressure at the limb is about the same as that of the air at Kodaikanal, or three-fourths of an atmosphere. It must be said however that some of the values of the limb — centre shifts are very uncertain and need revision, especially those which give low values for the total shift. If we eliminate from the lists the five lines which yield total shifts less than 10, the mean shift for the most affected lines would be + 0·0165 A, and for the least affected lines + 0·0149 A, a difference which would imply a total pressure at the limb of 1·27 atmosphere above the pressure at Kodaikanal, or about one atmosphere above normal pressure.

If the total pressure at the limb were of the order of 6 atmospheres, as might be deduced from the mean total shift of symmetrical lines which is almost + 0·015 A, then there should be a difference of shift between the lines most and least affected by pressure of 0·0075 A, a quantity which could not fail to appear in the mean results.

In this discussion we have taken no account of differences of level of the effective regions of absorption for the different lines. The reason is that the limb — arc shifts, as we have shown in table II, are not appreciably affected by differences of intensity. If the intensities of the lines near the limb are related to level in the same way as St. John has found for sun spots on the disk, then in the region of iron absorption level appears to have little or no effect on the displacements. For the symmetrical lines these are remarkably constant, not only for lines of greatly differing intensity but also for lines in very different regions of the spectrum.

Another reason for believing that the limb shifts are not due to pressure alone is furnished by the displacements of those iron lines which with increased pressure are shifted to the violet (Mt. Wilson group *e*) in contrast to the majority which are shifted to the red. For these lines we have only measures of limb — centre, the total shifts being unknown, but if the displacements at the limb of the majority of lines to the red is due to increased pressure alone then the lines of group *e* ought to be shifted to the violet. We have at present only two photographs of limb and centre containing lines of group *e* but their evidence is quite decisive, for each line is displaced to the red. These two plates include the regions λλ 5365 to 5455 and λλ 5555 to 5638, and the average displacement limb — centre is given in the following table, together with the pressure shift per atmosphere according to Gale and Adams *:—

TABLE V.

	Pressure shift per atmosphere.	Mean shift Limb – centre.
Lines displaced *slightly to the red* by increased pressure ... ... (λλ 5371, 5397, 5405, 5429, 5434, 5447).	+ 0·004 A.	+ 0·008 A.
Lines displaced *greatly to the red* by increased pressure ... ... (λλ 5393, 5565, 5569, 5573, 5576, 5586, 5603, 5615, 5624, 5638).	+ 0·023 A.	+ 0·008 A.
Lines displaced *greatly to the violet* by increased pressure ... (λλ 5365, 5383, 5411, 5415, 5424, 5555, 5565, 5598).	— 0·018 A.	+ 0·005 A.

The lines shifted to the violet by pressure have, it is seen, smaller displacements to the red than the other lines. Assuming that this relative shift is due to pressure, the deduced pressure at the sun's limb is, according to whether we compare these lines with the first or the second group in the table, one-seventh or one-fourteenth of an atmosphere above that at the centre of the disc; either of these amounts is comparatively insignificant. It should be mentioned, however, that the relative shift of these lines compared with the other lines is not *necessarily* due to pressure because we do not yet know the displacement at the centre of the sun, for in the arc the wave-lengths are not normal.† It may possibly be that the smaller displacement at the limb of the lines shifted to the violet by pressure will be compensated by a larger displacement at the centre as was shown above to be the case for lines of different intensities.

Limb shifts in relation to wave-length.

Our results do not confirm that large increase of shift with wave-length which Adams obtained with a much smaller number of lines. It is true that the relative shifts limb — centre tend to increase towards the red end of the spectrum, but this is counteracted by a decrease in the centre — arc shifts, so that the total

* Astrophysical Journal XXXVII, 391, 1913.

† See Kodaikanal Observatory Bulletin No. XXXVIII.

shift limb — arc remains sensibly constant whether we take all the lines of table I or only the symmetrical lines. These results are shown in table VI, where the lines of table I are grouped in three different regions of the spectrum, and the shifts for each group averaged. As in table II the lines 5162·449 and 5424·290 have been omitted.

TABLE VI.—MEAN SHIFTS IN RELATION TO WAVE-LENGTH.

Number of lines.	Region.	Limb — centre.	Centre — arc.	Limb — arc.
		(A) All lines except two.		
49	3895–4282	+ 0·0046 A	+ 0·0069 A	+ 0·0115 A
45	4308–4789	+ 0·0069	+ 0·0052	+ 0·0121
43	4859–5615	+ 0·0060	+ 0·0055	+ 0·0115
		(B) Symmetrical lines only.		
28	3895–4825	+ 0·0044 A	+ 0·0106 A	+ 0·0150 A
22	4837–5455	+ 0·0063	+ 0·0082	+ 0·0145

The symmetrical lines have been grouped in two regions only, owing to the small number of lines available. Both table A and table B exhibit the same characteristic inverse relation between the limb shift and the centre shift which results in sensibly constant values of the total shift, or limb—arc shift. The symmetrical lines give higher values, probably from the absence of the anomalous shifts caused by peculiar conditions in the arc.

If the total shifts at the limb were due to pressure we should expect to find a marked increase in the mean values for the less refrangible lines. For the symmetrical lines the mean pressure shift of the 28 more refrangible lines is 0·0025 A per atmosphere, and of the 22 less refrangible lines it is 0·0030 A per atmosphere. But the less refrangible lines represent lower levels in the reversing layer than the more refrangible lines, so that the mean limb shifts should increase in a greater ratio than 25 : 30. As they do not increase at all but tend to be smaller for the less refrangible lines, we conclude that pressure is not concerned in the general shift of the lines towards the red.

The Cyanogen Bands.

The shifts of the cyanogen bands at the limb and at the centre of the disk give additional evidence which is strongly against the view that pressure is the cause of the limb shifts, for the bands or flutings are not appreciably affected by pressure, and therefore the shifts found between limb and centre and centre and arc can only be explained by motion in the line of sight.

In the paper already cited Dr. Adams refers to his measures of the cyanogen flutings at λ 3883 and λ 4216, for which he finds a small positive shift limb — centre. His mean result for several plates and for 14 bands near 3883 is + 0·002 A. A few measures of these bands have also been made at Kodaikanal with results which confirm Adams' measures, showing a relative shift to red at the limb which is notably smaller than that of the iron or titanium lines. The mean shift limb — centre of the best defined bands is + 0·002 A from 5 plates.

The values vary considerably from plate to plate, and Adams considered this shift to be due to ascending movements of the cyanogen at the centre of the disk, causing a violet shift at the centre or a relative shift to red at the limb.

Obviously the determination of the absolute shifts of the CN bands at the centre of the disk compared with the bands in the carbon arc is of crucial importance in testing Adams' hypothesis and in connection with limb shifts generally. Accordingly we have made very careful sets of measures of the bands near 3883 in eight comparison spectra of the carbon arc and the centre of the disk, using carbon terminals or one terminal carbon and the other iron.

In table VII the mean results are given for two sets of measures of 4 plates, each by different measurers, the initials N, N, R, and E at the head of columns 2 and 3 indicate the measurers Nagaraja Ayyar, Narayana Ayyar, Royds and Evershed respectively.

TABLE VII.—SHIFTS OF CN BANDS AT CENTRE OF DISK IN A/1000.

λ (Rowland).	N.N.R. (4 plates).	E. (4 plates).
3863·533	+ 10	...
3864·438	+ 10	+ 7
3876·448	− 6	+ 1
3876 {·556, ·622}	+ 6	+ 4
3877 ·481	− 2	+ 1
3877 {·587, ·646}	+ 6	+ 6
3879 {·331, ·394, ·458}	...	+ 5
3879 {·796, ·851}	...	+ 3
3880 {·465, ·532, ·596}	...	+ 7
3880 {·815, ·931}	+ 5	+ 4
3881 {·729, ·825}	+ 8	+ 7
3882 {·828, ·893}	+ 9	+ 7
Means	+ 0·0052 A	+ 0·0045 A

Each set of 4 plates was photographed independently at different dates and required different corrections, to be applied for the earth's movements relative to the sun. The lines or bands chosen for measurement were those most clearly defined in the sun and free from evidence of any interference by lines due to other substances. All of them are assigned by Rowland to C only. As the two sets of measures were made quite independently rather a different selection was made, but the agreement of the values for the common lines is as good as could be expected considering the breadth of many of the bands of which the component lines are only partially resolved in the photographs. There is a general agreement also in the differences of shift for the different lines or bands, showing that these differences are not due to errors of measurement, but are possibly due to the peculiar conditions in the arc, which as we have shown tend to produce small, or even negative, sun — arc shifts in the case of some of the iron lines. The two lines 3876·448 and 3877·481 which give negative shifts in the first set of measures and small positive shifts in the second set would seem to be affected in this way, and the difference in the measures may be due to a shorter arc having been used in the first set of photographs than in the second.

Both sets of measures agree in showing a general shift of the CN bands to the red at the centre of the disk amounting to + 0·005 A, a value which is almost certainly too small, as the general effect of the arc conditions is to reduce the sun — arc shifts. If the lines giving negative shifts are excluded the general mean becomes + 0·0064 A, equivalent to a motion of *descent* on the sun of 0·50 km/sec. This is the same order of velocity as we have found for iron in the reversing layer, being intermediate between the velocities obtained from the high level and low level iron lines. According to St. John the CN bands represent a rather low level in the solar atmosphere, or about a mid-level in the reversing layer, so that the velocity found above is in strict harmony with our results for iron.

As the cyanogen gas in the sun is descending at the centre of the disk and not ascending, the limb — centre shifts to the red cannot be explained as due to a violet shift at the centre. If the limb — centre and centre — arc shifts are added, the total or limb — arc shift amounts to about + 0·008 A, indicating a recession at the limb parallel to the solar surface of 0·62 km/sec. But this movement of recession at the limb suggests a similar movement for iron and other elements. For iron the total shift at the limb is as we have shown + 0·015 A for the symmetrical lines, and almost constant for different spectral regions. This would imply velocities varying from 1·1 km/sec. at λ 4000 to 0·9 km/sec. at λ 5000.

The velocity interpretation of the limb shifts of the iron lines seems forced upon us by the CN shifts, and involves very remarkable consequences, for we have to suppose the iron and other gaseous substances receding from the earth at opposite points on the sun's limb, at the centre, and by inference all over the disk and all round the circumference, the velocity increasing from the centre of the disk towards the limb where, unimpeded by the denser gases at the base of the reversing layer, it attains a velocity of about 1 km/sec.

But a movement constant in direction relative to the earth and maintained at all seasons of the year means an earth effect—an actual repulsion of the solar gases by the earth, and not apparently by the other planets.

While fully appreciating the absurdity of this idea we feel that there may be some justification for it in the apparent influence of the earth on the distribution of sunspots on the visible disk and of the prominences on the east and west limbs. That the earth exerts some sort of influence on solar phenomena which is not shared by the other planets is a startling and perhaps incredible supposition, but the facts which have recently been disclosed in this connection have not yet been explained otherwise.

There appears in fact to be no alternative to this earth-effect hypothesis, at any rate with regard to the cyanogen shifts at the limb, unless we assume some cause for line shifts other than motion or pressure. According to the "Theory of Relativity" of Einstein, the sun's gravitational field should diminish the frequency of the light emitted, and the mean shift to the red found by us at the centre of the disk agrees very closely with the theoretical gravitational shift calculated by E. F. Freundlich.* But the large variations of shift from line to line at the centre of the disk which depend mainly on intensity, and the constancy of the limb shifts for different wave-lengths are facts which would apparently offer serious difficulties to this explanation. One of us has found † that the displacement at the centre of the sun's disk decreases rapidly with depth; it would presumably vanish at a depth a little lower than that of the faint iron lines whilst the gravitational force can only be slightly smaller than at higher levels and may, indeed, be larger.

Summary.—The main results of this investigation and the conclusions reached may be briefly recapitulated in the following paragraphs :—

(1) In studying the limb shifts it is considered essential to determine the total shifts limb — arc instead of the relative shifts between limb and centre of disk as has been done hitherto.

(2) The total shifts of 139 iron lines at the sun's limb have been determined by adding the limb — centre shifts to the centre — arc shifts, and also directly in some cases by measuring the limb — arc shifts.

(3) The limb — centre shifts and the centre — arc shifts are found to be related to the intensity of the solar lines in an opposite sense, the former decreasing as the intensity increases and the latter increasing at about the same rate. The total or limb — arc shifts are therefore approximately constant for all intensities.

(4) The relation between limb — arc shifts and pressure shifts is discussed for all the lines with known pressure shifts. Grouping the lines into those more or less affected by pressure and into different spectral regions, it is found that the more affected lines are much less shifted than the less affected. This result is believed to be partly due to certain peculiar conditions in the arc which tend to reduce the sun — arc shifts, and especially the shifts of those lines most affected by pressure.

(5) Taking symmetrical lines only, which are presumably free from the disturbing effects of the arc conditions, there is found to be no difference of shift between groups of lines whose average pressure shifts differ in the ratio 1·6 to 1. This implies a pressure in the effective region of absorption at the limb equal to that of the air at Kodaikanal or $\frac{3}{4}$ atmosphere, a result which may however be considerably modified by further research.

(6) The large shifts of the symmetrical lines at the limb, amounting to 0·015 A towards the red, cannot be due to pressure because, if so, the differential shifts of the lines more and less affected by pressure would be of an order of magnitude which could not fail to appear in the measures. Moreover the pressure hypothesis requires that certain iron lines should be displaced at the limb to the violet whereas they are actually shifted to the red of their positions at the centre of the disk.

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* Physikalische Zeitschrift XV, 2, 1914.

† Kodaikanal Observatory Bulletin No. XXXVI.

(7) It is shown that although the relative shifts, limb — centre, of the iron lines tend to increase toward the longer wave-lengths, the total shifts, limb — arc, remain remarkably constant when means are taken in three spectral regions between λ 3895 and λ 5615. This constancy of shift is also shown strikingly by the symmetrical lines alone, and tells heavily against the pressure theory.

(8) The constancy of the limb — arc shifts for symmetrical lines of greatly differing intensity shows that level is not an important factor in determining the limb shifts, if it may be assumed that intensity is related to level for lines near the limb as it appears to be for lines in sunspots on the disk.

(9) The cyanogen bands are shown to be displaced towards the red at the limb relatively to the centre of the disk, and at the centre compared with the arc. As these bands are not shifted appreciably by pressure the shifts can only be explained by assuming a movement of recession from the earth—a descending motion on the disk and a movement parallel to the solar surface at the limb. The total shift is about 0·008 A, indicating a recession near the limb of 0·62 km. per sec.

(10) The shifts of the iron lines, amounting to a mean value of 0·015 A for the symmetrical lines, is interpreted similarly as due to a recession of the iron vapour at the limb of about 1 km. per sec. A movement of recession from the earth at the centre and over the entire disk also follows.

(11) The view that the solar gases are actually repelled by the earth receives some support from other lines of evidence, but an alternative hypothesis is considered, namely, that the sun's gravitational field affects the wave-length of the light emitted, in accordance with Einstein's Theory of Relativity.

KODAIKANAL,
1st *June* 1914.

J. EVERSHED.
T. ROYDS.

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Kodaikanal Observatory.

BULLETIN No. XL.

AN INVESTIGATION OF THE DISPLACEMENT OF UNSYMMETRICAL LINES UNDER DIFFERENT CONDITIONS OF THE ELECTRIC ARC.

By T. ROYDS, D.Sc.

Whilst investigating the suitability of iron lines as standards of wavelength, St. John and Miss Ware found that in one of their photographs the wavelengths of lines of their group *d* were longer, and of group *e* shorter, than in other photographs [1], and Goos has concluded that the wavelengths of certain iron lines vary with current, arc length and region of the arc [2]; also Fabry and Buisson detected shifts of opposite signs for the two kinds of unsymmetrical lines when the current in the arc was increased [3]. I have been led to similar results in the course of a comparison of the spectrum of the centre of the sun's disc with that of the electric arc [4]. In these experiments I found that when a short arc had been employed the solar displacements were for certain lines systematically different from those when a long arc had been used for comparison with the sun. This suggested a direct comparison of the centre of a short arc with the centre of a long arc, and it was found that the iron lines of group *d* and certain of group *c* (*i.e.*, lines unsymmetrically widened towards the red) were displaced in the short arc to the red, and the lines of group *e* (unsymmetrical towards the violet) to the violet, whilst symmetrical lines were practically undisplaced.

The existence of this displacement affecting almost exclusively those lines which are most shifted by pressure, seriously limits our means of estimating the pressure shifts in the sun. Also there is evidence that the wavelengths of the lines which are liable to undergo displacements are not normal even at the centre of a very long arc, for many of the solar displacements given in Table IX of Kodaikanal Observatory Bulletin No. XXXVIII are so large as not to be explained as due either to pressure or to motion in the line of sight. It is therefore of pressing importance to investigate the cause of the displacements which occur in different conditions of the electric arc, and to find a light source giving normal wavelengths for all classes of lines.

Experimental details.—The spectrograph employed for this investigation has been described elsewhere [5]. The third order spectrum was generally used except for regions less refrangible than λ 5800 for which the second order was used. The dispersion in the third order varies from 0·9 A per mm. at λ 3950 to 0·6 A per mm. at λ 5680.

The electric arc was supplied by a battery of 110 volts; the poles were vertical and an image, enlarged $3\frac{1}{4}$ times, was formed on the vertical slit of the spectrograph by means of a condensing lens. The comparison of the spectra from two different parts of the arc was made by means of an occulting screen sliding in front of the slit. The comparison spectrum was in every case the central portion of a long arc and was impressed on the photographic plate above and below a spectrum in the middle to be compared with it. Half of the exposure of the comparison spectrum was given immediately before exposing the middle spectrum, and the second half immediately afterwards. This guarded against the possibility of shifts due to temperature

(1) St. John and Miss Ware, Astrophysical Journal, XXXIX, 5, 1913.
(2) Goos, Astrophysical Journal, XXXVII, 48, 1913 and XXXVIII, 141, 1913.
(3) Fabry and Buisson, Astrophysical Journal, XXXI, 97, 1910.
(4) Royds, Kodaikanal Observatory Bulletin No. XXXVIII.
(5) Evershed, Kodaikanal Observatory Bulletin No. XXXVI.

changes or to mechanical disturbances passing unnoticed. A graduated scale on the occulting screen enabled the length of the arc to be controlled.

The atmosphere surrounding the arc was air at ordinary pressure (580 mm. at the level of the Observatory) or at reduced pressure. For the iron and copper arc metallic poles were used; in the cases of other elements salts were introduced on one or both poles of a carbon arc.

Investigation of Iron Lines.—It was found previously that the displacements of the iron lines in the short arc were associated with the unsymmetrical character of the lines; lines widened more towards the red were found to be displaced to the red, and those widened more towards the violet to the violet, whilst symmetrical lines were undisplaced. For the present purpose therefore spectrum lines may be classified as symmetrical (marked s in the tables), those widened unsymmetrically towards the red (marked ur) and those widened unsymmetrically towards the violet (marked uv). The study of the iron lines has been confined to two regions of the spectrum, namely, λλ 5365—5455 and λλ 5555—5638; these regions include 7 symmetrical lines and 16 strong unsymmetrical lines, 8 being widened more towards the red and 8 towards the violet.

The measured displacements of these iron lines under different conditions are given in Table I.

TABLE I.—DISPLACEMENTS OF IRON LINES IN A/1000.

λ (Rowland).	Centre of arc 2 mms. long — Centre of arc 7 mms. long.	Negative Pole — Centre (arc 7 mms. long).	Positive Pole — Centre (arc 7 mms. long.	Negative Pole (arc 2 mms. long) — Centre (arc 7 mms. long).	Positive Pole (arc 2 mms. long) — Centre (arc 7 mms. long).	Centre of arc (7 mms. long) at 9½ amps. — Centre of arc (7 mms. long) at 4½ amps.	Centre of arc (2 mms. long) at 8½ amps. — Centre of arc (2 mms. long) at 3¾ amps.
No. of Photographs ..	1	7	1	2	2	1	1
5371·734 (s)	+ 1	+ 1	0	+ 2	0	− 1	+ 2
5397·314 (s)	− 1	+ 1	− 1	+ 2	0	0	+ 3
5405·989 (s)	0	+ 1	+ 1	+ 1	0	− 1	+ 2
5429·911 (s)	− 1	+ 1	0	+ 1	0	− 1	0
5434·740 (s)	+ 1	0	0	+ 3	− 1	− 1	+ 2
5447·130 (s)	− 1	0	0	+ 2	0	− 2	− 4
5455·834 (s)	− 2	0	− 1	+ 1	0	− 1	− 2
Mean (s)	− ·0004 A	+ ·0006 A	− ·0001 A	+ ·0017 A	− ·0001 A	− ·0010 A	+ ·0004 A
5393·375 (ur)	+ 4	+ 12	− 1	+ 12	+ 2	+ 3	+ 8
5569·848 (ur)	+ 7	+ 10	+ 5	...	...	+ 3	...
5573·075 (ur)	+ 8	+ 10	+ 5	...	...	+ 2	...
5576·320 (ur)	+ 10	+ 16	+ 6	...	...	+ 5	...
5586·991 (ur)	+ 6	+ 11	+ 3	...	...	+ 3	...
5603·186 (ur)	+ 6	+ 12	...	...	...	+ 2	...
5615·877 (ur)	+ 9	+ 10	+ 5	...	...	+ 2	...
5624·769 (ur)	+ 5	+ 11	+ 3	...	...	+ 1	...
Mean (ur)	+ ·0069 A	+ ·0115 A	+ ·0043 A	+ ·012 A	+ ·002 A	+ ·0026 A	+ ·008 A
5365·069 (uv)	− 10	...	...	...	...	...	...
5367·669 (uv)	− 12	− 12	− 7	− 11	− 5	...	− 13
5370·166 (uv)	− 8	− 11	− 3	− 6	− 4	− 3	− 9
5383·578 (uv)	− 9	− 13	− 8	− 9	− 4	− 5	− 7
5404·357 (uv)	− 8	− 12	− 5	− 10	− 6	− 4	− 9
5411·124 (uv)	− 10	− 12	− 7	− 9	− 5	− 5	− 12
5415·416 (uv)	− 12	− 12	− 6	− 7	− 6	− 8	− 14
5424·290 (uv)	− 12	− 13	− 6	− 7	− 5	− 10	− 11
Mean (uv)	− ·0101 A	− ·0121 A	− ·0060 A	− ·0084 A	− ·0050 A	− ·0058 A	− ·0107 A

It is seen from the table that only unsymmetrical lines undergo any notable displacement and these always in the direction of greater widening. How far this result is due to errors of estimating the correct position of the maximum intensity in an unsymmetrical line is discussed below. The largest displacements occur in the region near the negative pole of the iron arc; at the positive pole the displacement is about half that at the negative pole. A considerable displacement is also produced by shortening the arc (as was shown for other lines in Bulletin No. XXXVIII) or by increasing the current through the arc.

Fig. 1 of the accompanying plate is a three times enlargement of a portion of a photograph comparing the spectrum of the region near the negative pole with the centre of the arc and shows the different behaviour of the three lines λ 5383 (uv), λ 5393 (ur), and λ 5397 (s).

Investigation of the Calcium Triplet near λ 4580.—Since the sun and arc comparisons detailed in Kodaikanal Observatory Bulletin No. XXXVIII showed that the solar displacements of certain lines of some elements were much more abnormal than those of the iron lines, it was to be expected that these lines would also give larger displacements under varying arc conditions. The calcium triplet at λ 4580 was selected as being most convenient for investigation. In Table II are given the displacements measured using an arc between carbon poles on one of which a little calcium chloride had been placed. The displacement at the negative pole is greater than one-tenth of an Angstrom unit for each line of the triplet when the salt has been placed on the negative pole, and is not appreciably greater when the salt has been placed on both poles; one photograph illustrating the displacement is shown enlarged 3 times in fig. 2 of the accompanying plate. The average displacement at the negative pole of the line λ 4607·510 (due to strontium impurity) on the same photographs is + 0·0004 A.

TABLE II.—DISPLACEMENTS OF THE CALCIUM TRIPLET NEAR λ 4580 IN THE CARBON ARC IN AIR.

λ (Rowland.)	Negative Pole — Centre (Arc 12 mms. long).		Positive Pole—Centre (Arc 12 mms long).	
	Salt placed on − pole.	Salt placed on + pole.	Salt placed on − pole.	Salt placed on + pole.
Number of photographs.	3	4	1	1
4578·732 (ur)	+ 101	+ 51	+ 59	+ 50
4581·575 (ur)	+ 113	+ 62	+ 63	+ 56
4586·047 (ur)	+ 125	+ 69	+ 68	+ 58
Mean	+ ·113 A	+ ·061 A	+ ·063 A	+ ·055 A

When the salt is placed on the positive pole only, the displacement at the negative pole is reduced by nearly one-half and becomes about equal to the displacement at the positive pole. For the positive pole the displacement is approximately the same on whichever pole the salt has been placed. The result that the displacement at the negative pole is greater when the calcium salt has been placed on that pole is of great importance in tracing the cause of the displacements. In order to keep the calcium content of the arc more constant than it is possible to obtain by placing a salt on the poles, the "flame" arc was also employed to produce these lines, the measures being given in Table III. The displacement is of the same order as that when the carbon arc is supplied with calcium salt, and when the flame arc carbon is the positive pole and an ordinary arc carbon the negative, the displacement at the negative pole is less than half that when both poles are flame arc carbons.

TABLE III.—DISPLACEMENTS OF THE CALCIUM TRIPLET NEAR λ 4580 IN THE "FLAME" ARC IN AIR.

λ (Rowland)	Negative Pole—Centre (Arc 15 mms. long).			Positive Pole—Centre (Arc 15 mms long).		Centre of arc (6 mms. long) at 9 amps. —Centre of arc (6 mms. long) at 3 amps.
	Both poles flame arc carbons.	+ pole, flame arc carbon − pole, ordinary carbon.	+ pole, ordinary carbon − pole, flame arc carbon.	Both poles flame arc carbons.	+ pole, flame arc carbon − pole, ordinary carbon.	
Number of photographs.	4	2	2	3	2	2
4578·732 (ur)	+ 128	+ 49	+ 77	+ 59	+ 57	+ 34
4581·575 (ur)	...	+ 47	+ 60	+ 47	+ 49	+ 28
4586·047 (ur)	+ 137	+ 57	+ 86	+ 56	+ 62	+ 37
Mean ...	+ ·132 A	+ ·051 A	+ ·074 A	+ ·054 A	+ ·056 A	+ ·033 A

Displacements of the Calcium Triplet near λ 4580 *in the Arc in Vacuo.*—The displacements of these lines in the "flame" arc in vacuo are very much smaller than in the arc in air, but they undoubtedly exist and

probably under all the conditions in which they occur in the arc in air. The displacement near the negative pole disappears at less than a millimetre from the pole so that if the arc burns into a cavity in the electrode the shift is not seen at all. The displacements observed in the arc at about 8 cms. pressure are given in Table IV. The shift at the negative pole is about one-ninth of that in the arc in air, and there is a shift due to increase of the current strength. The largest displacement occurred when the region near the negative pole at 8 amperes was compared with the centre of the arc at $8\frac{1}{2}$ amperes; even then the mean displacement of the triplet amounted only to 0·024 A. These lines are probably very sensitive to pressure but since this did not vary more than a millimetre during an experiment the displacements are not due to pressure.

TABLE IV.—DISPLACEMENTS OF THE CALCIUM TRIPLET NEAR λ 4580 IN THE "FLAME" ARC IN VACUO.

λ (Rowland.)	Negative Pole – Centre of Arc.	Centre of arc at 8 amps. – Centre of arc at $8\frac{1}{2}$ amps.	Negative Pole of arc at $7\frac{1}{2}$ amps – Centre of arc at $8\frac{1}{2}$ amps.
Number of photographs.	2	1	1
4578·782 (ur)	+ 10	+ 8	+ 23
4581·575 (ur)	+ 9	+ 5	+ 5
4586·047 (ur)	+ 10	+ 6	+ 23
Mean	+ ·010 A	+ ·006 A	+ ·024 A

Displacements and Phenomena near the Negative Pole of the Arc.—The light from the neighbourhood of the negative pole is much more intense than that from the centre of the arc. When a calcium, or other, salt has been introduced into a carbon arc there can be seen near the negative pole a well-defined region of intensely luminous vapour extending more or less towards the centre of the arc according to the quantity of salt introduced; at the positive pole there is a similar intense region less luminous and extensive. Even with the enlarged image of the arc projected on the aluminium occulting screen in front of the slit, the intense region near the negative pole was very trying to the unprotected eye. It is in this intensely luminous region near the poles that the displacement occurs; in the parts of the arc outside it, though still distant from the centre, the displacement is very small compared with that in the parts within its limits. A series of photographs of the calcium triplet near λ 4580 in the flame arc was taken comparing the spectrum of different distances from the negative pole with the spectrum of the centre of the arc. The length of the image of the arc was kept constant at 2 inches and the mean displacement of the two lines λ 4578 and λ 4586 were as follows:—

Distance from image of negative pole	Displacement compared with centre of arc.
1 mm. (inside intense region)	+ 0·132 A
3 ,, (,, ,,)	+ 0·107 A
9 ,, (just on limit of intense region)	+ 0·022 A
16 ,, (outside intense region)	+ 0·008 A
25 ,, (centre of arc)	(0·000 A)

The results for the iron lines and the calcium triplet near λ 4580 show that to investigate the relative behaviour of spectrum lines it is sufficient to confine the experiments to a comparison of the spectrum near the negative pole with that of the centre of the arc. It would take a long time to investigate the behaviour of all lines of every element, even of only unsymmetrical lines, but such a course is hardly necessary in order to show the characteristic features of the different types of lines and the displacement at the negative pole. Various types of unsymmetrical widening are met with even in the comparatively small number of lines which have been photographed. Some of the broad lines have large displacements, others small, depending on the amount of dissymmetry; some lines have one edge fairly sharp, others have both edges diffuse; lines which are comparatively narrow may be very unsymmetrical and undergo large displacement.

The majority of the unsymmetrical lines investigated are widened towards the red, but some were also chosen which are widened towards the violet.

Table V contains the results for all the lines which have been photographed. The second column quotes the character of the lines as given in Kayser's tables [1], chiefly from the data of Kayser and Runge, Exner and Haschek or Eder and Valenta. The direction of unsymmetrical widening can be seen in the spectrum of the region near the negative pole even of many lines whose character is not given by these authorities, but the most sensitive test is the direction of displacement.

TABLE V.—DISPLACEMENTS AT THE NEGATIVE POLE OF A LONG ARC COMPARED WITH THE CENTRE OF THE ARC.

λ (Rowland)	Character.*	Displacement in A/1000. Negative Pole – Centre. Unreversed.	Reversed.	⊙ – Centre of arc.†
Aluminium.				
3944·160 (s)	...	+ 4	...	+ 3
3961·674 (s)	...	+ 4	...	+ 2
Barium.				
4239·91 (ur)	ur	+111	...	...
4242·83 (ur)	ur	+ 57	...	...
4264·45 (uv)	u	− 52	...	...
4283·27 (ur)	ur	...	+ 10	...
4291·32 (ur)	...	+ 11	.	...
4323·15 (uv)	uv	−157	...	...
4325·38 (ur)	...	+ 54	...	...
4333·04 (uv)	u	− 24	...	...
4350·49 (ur)	ur	+166	+ 3	...
4359·80 (ur)	...	+ 48	...	...
4467·36 (ur)	..	+ 50	...	. .
4489·50 (uv)	uv	− 45	...	...
4498·82 (uv)	uv	− 42	...	...
4506·11	...	...	0	...
4523·48 (ur)	...	...	− 11	...
4525·19 (ur)	ur	+ 44	...	...
4554·211 (s)	...	...	0	− 5
4574·08 (ur)	...	..	+ 8	...
4579·84 (ur)	...	...	+ 10	...
4673·69 (uv)	uv	−118	...	...
4691·74 (ur)	...	...	+ 4	...
4700·64 (ur)	ur	+216	...	...
4726·63 (ur)	...	...	+ 14	...
6063·33 (ur)	...	+ 37	+ 21	...
6111·01 (ur)	...	+ 39	+ 14	...
6141·93 (ur)	...	+ 62	...	...
Calcium.				
3933·825 (s)	..	...	+ 2	...
3957·177 (ur)	ur	+ 14	...	...
3968·625 (s)	...	...	− 2	...
3973·864 (ur)	ur	+ 17	...	...
4092·821 (ur)	ur	+107	..	...
4283·16	...	...	0	+ 6
4289·525 (uv)	...	− 9	+ 1	+ 10
4299·149 (uv)	...	− 11	− 2	+ 6
4302·692	...	...	0	+ 10
4307·907 (uv)	...	− 11	− 2	...
4318·817 (uv)	uv	− 12	− 2	...
4425·608	u	...	+ 3	+ 2

λ (Rowland.)	Character.*	Displacement in A/1000. Negative Pole – Centre. Unreversed.	Reversed.	⊙ – Centre of arc.†
Calcium (*cont.*)				
4435·129	u	...	+ 2	+ 3
4435·851	...	...	+ 2	+ 2
4454·953	u	.	− 1	...
4456·794	...	...	0	+ 7
4527·101 (ur)	ur	+173	...	− 44
4578·782 (ur)	...	+101	...	− 25
4581·575 (ur)	...	+113	...	− 24
4586·047 (ur)	ur	+125	...	− 30
5857·674 (ur)	u	+ 111	...	...
6102·937 (ur)	..	+170	+ 21	− 27
6122·434 (ur)	...	+190	+ 14	− 24
6162·390 (ur)	...	+233	+ 15	− 28
6169·249 (ur)	...	+ 40	...	...
6169·778 (ur)	...	+ 42	...	...
Copper.				
4531·04 (ur)	...	+ 34	...	...
4587·19 (ur)	u	+ 24	...	...
Iron §.				
4045·975 (s)	...	0	...	+ 9
4063·759 (s)	...	− 2	...	+ 7
4071·908 (s)	...	− 2	...	+ 10
4325·939 (s)	..	+ 2	...	+ 12
4383·720 (s)	...	+ 1	...	+ 8
4404·927 (s)	...	+ 2	...	+ 7
Magnesium.				
4352·083 (ur)	ur	+ 75	...	...
5167·497 (ur)		+ 14	...	− 10
5172·856 (ur)	...	+ 13	...	− 7
5183·791 (ur)	..	+ 12	...	− 9
Sodium				
5682·869 (ur)	ur	+ 321 ?	− 19	− 127
5688·486 (ur)	ur	+ 392 ?	− 19	− 144
6154·438 (ur)	ur	+ 523	...	− 81
6160·956 (ur)	ur	+ 513	...	− 79
Strontium.				
4607·510 (s)	...	+ 1	...	+ 1

* From the Tables in Kayser's Handbuch der Spectroscopie, Vols. V and VI.
† From Kodaikanal Observatory Bulletin No XXXVIII.
§ See also Table I, column 3.

It is seen from the table that, as found from iron lines, whilst symmetrical lines undergo very small, if any displacement unsymmetrical lines are displaced in the direction of their greater widening. Not a single exception to this has yet been met with; of lines which were previously known, or are now found, to be

[1] Kayser, Handbuch der Spectroscopie Vols. V and VI.

unsymmetrical, all are displaced (provided they are unreversed) either to the red or to the violet according to the direction of unsymmetrical widening. The fact of the displacement being dependent on the unsymmetrical character of the line makes it essential to remove any possibility of doubt that the displacements are not due to errors of estimating the true maximum of intensity of an unsymmetrical line since the tendency of the error is probably also in the direction of greater widening. This point is discussed below.

When an unsymmetrical line is reversed at the negative pole the displacement of the reversal is much smaller than that of the unreversed line; in the case of the sodium pair λλ 5682, 5688 (both ur) the reversal is displaced to the violet. The significance of these facts will be discussed later.

The dependence of the shifts on the unsymmetrical widening of lines seems to outweigh that on any other characteristics. For instance, the shift to the violet of the first subordinate series of barium is not characteristic of all first subordinate series but happens with barium since its series is unsymmetrically widened towards the violet. Similarly the shift tends to increase as we pass down a series only because the unsymmetrical widening becomes greater.

Reality of the Displacement of Unsymmetrical Lines.—The practice of dividing the exposure of the comparison spectrum into two halves, one before and the other after the middle strip of the photograph was exposed on the part of the arc to be investigated, has removed the possibility of fictitious shifts being undetected. A further safeguard has been the presence of symmetrical lines on nearly every photograph; the fact that these lines suffer no displacement at once shows that the shifts of other lines are not spurious.

The dependence of the displacements on the unsymmetrical character of the lines makes it necessary to consider very carefully the error which enters into the estimation of the portion of maximum intensity of an unsymmetrical line, for the direction of the error is probably in the same direction as the displacements found. The error of measurement of the position of maxium intensity of a broad unsymmetrical line cannot be small, but it is perfectly clear from the photographs reproduced in the accompanying plate that a real displacement exists whose magnitude cannot be considerably affected by any possible error of measurement. In figure 2 especially is this obvious, where the lines of the region near the negative pole stand quite clear of those of the centre of the arc, and similar cases are frequently met with. In order to obviate as much as possible the false displacement due to errors of measurement, I have in the case of some of the iron unsymmetrical lines underexposed the widened lines until they appeared of the same width as those in the comparison spectrum. Under these conditions it may be assumed that the degree of unsymmetrical widening would be the same in the two spectra and the errors of estimating the position of the maximum intensity would be the same in both cases. Nevertheless, the measured displacement is still of quite the same order as in fully exposed photographs.

It might be argued that the displacements are apparent only, being due to the complete absorption of one side of the unsymmetrical line by the outer portion of the arc, leaving visible in the photograph really only a portion of the line apparently displaced[1]; on this view the emission line from the inner portion of the arc, as well as the absorption line from the outer regions are supposed, if it were possible to isolate them, to be undisplaced. In the sodium pair λλ 5682, 5688, the absorption line can be seen under proper density conditions to be almost at the very edge of the emission line, and it is easy to conceive of a case a little more extreme in which the absorption line actually reaches to the edge leaving only one component of the emission line visible. The argument might conceivably hold for some cases but it cannot apply to the majority. It must be remembered that the displacement can be made, by choosing the proper portion of the arc, to have any value from zero up to the maximum observed at the negative pole, and the smaller displacements occur with the line so broad that any undisplaced absorption line must be visible. Indeed so far from having to suppose an absorption line not shifted, the actual absorption line observed in reversed lines is in many cases displaced, a fact which disposes of the hypothesis.

The possibility of anomalous dispersion in the arc must also be considered. It is conceivable that at the negative pole, for example, there is a density gradient sufficient to cause wavelengths on each side of

[1] Exner and Haschek believe this to be possible (Die Spektren der Elemente bei Normalem Druck, Vol. I., p., 28.)

the absorption line, for which the refractive index would be abnormal, to be refracted out from the direction of the condensing lens and missing from the spectrum. There are, however, several facts against the anomalous dispersion hypothesis. Firstly, it fails to account for the displacement of unreversed lines. Secondly, for some of the lines widened unsymmetrically towards the red, the displacement of the reversal is to the red (*e.g.*, the calcium lines λλ 6102, 6122, 6162) and for others to the violet (*e.g.*, the sodium lines λλ 5682, 5688); these cannot be reconciled by the hypothesis. Thirdly, the unsymmetrical lines undergo large sun—arc displacements whose signs are opposite to those of the displacements at the negative pole; the existence of an anomalous dispersion band in the apparent absorption line does not assist in any way in explaining these shifts.

There is also the possibility of the displacement being due to the enhancement of a satellite on one side which blends with the principal line to produce apparently a single line displaced. A satellite is known to exist for example, on the red side of the calcium line λ 4586 shown in fig. 2; but to account for the greatly varying displacements which can be obtained in different portions of the arc, we must suppose that not only is the satellite enhanced until stronger than the principal line, but also is itself displaced. Besides, many lines known to be single are displaced.

The Cause of the Displacement of Unsymmetrical Lines under different conditions of the Electric Arc.—In Kodaikanal Observatory Bulletin No. XXXVIII, I have suggested that differences of density are the cause of the displacements between the short and the long arc, and presumably, between the sun and the long arc. There is now a considerable amount of evidence to elucidate the origin of the displacements under different arc conditions, and density is the only cause which can explain all the phenomena. Very significant are the following facts:—

(*a*) When the current strength is increased, thus increasing the amount of vapour in the arc, the lines are displaced in the same direction as at the negative pole. With an iron arc of 2 mms. length doubling the current strength produced a mean displacement of — 0·011 A for seven lines unsymmetrical towards the violet or nearly equal to that between the negative pole and centre of the long arc for the same lines (see Table I); with an iron arc 7 mms. long doubling the current strength did not, from the appearance and sound of the arc itself, produce nearly so great a difference in the rate of production of vapour and the displacement was smaller. Increasing the current in a "flame" arc 6 mms. long also produced a displacement of the calcium triplet near λ 4580 of + ·033 A.

(*b*) The displacement of the calcium triplet near λ 4580 at the negative pole is larger when the salt has been placed on that pole than when on the positive; with the flame arc the displacement at the negative pole is larger when both poles are flame arc carbons or when the negative pole only is a flame arc carbon, than when the positive pole only is a flame arc carbon.

(*c*) When an unsymmetrical line is reversed at the negative pole, as frequently is the case, the displacement of the reversal is much smaller than would be expected in an unreversed line of the same degree of unsymmetrical widening. There are many cases, such as the calcium triplet λλ 6102, 6122, 6162, which are reversed in one photograph (calcium salt placed on the poles) and unreversed in another (sodium salt with calcium impurity placed on the poles); the displacements of the emission lines of the triplet in the latter average + 0·198 A and of the absorption line in the former + 0·015 A.

(*d*) Take the example of the sodium pair λλ 5682, 5688. As mentioned previously, the reversal of those lines appears under certain conditions of vapour density, almost at the violet edge of the lines. The reversal is so far to the violet that the maximum of the emission lines appears quite undisturbed by the absorption, as has been observed by Duffield in the case of certain iron lines under pressure [1] and by others; on this assumption the emission line at the negative pole is displaced by + 0·36 A, an amount not inconsistent with the solar displacement. Whether the displacement is so great as this may be doubtful, but it is at any rate practically certain that the displacement of the emission line for lines so obviously unsymmetrical towards the red is to the red. It is, therefore, important to note that the reversal is displaced by — 0·019 A, that is to the violet, of the line at the centre of the arc or in the direction opposite to that of the emission line.

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[1] Duffield, Phil. Trans. Roy. Soc. A. 208, 111, 1908.

(e) The displacements exist in those parts of the arc where the lines are widened and are greatest where the widening is greatest. The cause of the displacement may be the same as that of the widening i.e., either density, temperature, or some electrical effect such as ionisation, but the effect of increasing the quantity of material in the arc on the width of lines is so obvious that this is probably the chief cause.

The explanation of the reversal phenomena on the density hypothesis is obvious. The vapour in the outer regions of the arc is of low density (and low temperature) and therefore produces a narrow absorption line superposed on the broad emission line due to the vapours of high density (and high temperature) in the inner regions. The displacements of the absorption line at the negative pole will therefore not be so great as that of the emission line, and may, when the density of the absorbing layer is smaller than that at the centre of arc (which gives the comparison spectrum), be displaced in the opposite direction.

The fact that the shift at the negative pole is greater than that at the positive, implying greater density of vapour there, may be explained as due to the metallic ions, which would carry a positive electric charge being carried over to the negative pole by the electrical field.

There may be other hypotheses brought forward to explain the displacement of unsymmetrical lines, the most important of which is pressure. The iron lines which undergo displacement under different conditions of the arc, are those which have large pressure shifts, and the directions of displacement are those which would result from an increased pressure in the arc due to a sudden production of vapour at the poles. The amount of pressure required to produce the observed displacements can be calculated, as is done in Table VI. It is altogether inconceivable that pressures of 8 atmospheres above atmospheric can be produced locally in the arc burning in free air at atmospheric pressure.

TABLE VI.—PRESSURE NECESSARY TO PRODUCE THE MEASURED DISPLACEMENTS.

Line and element.	Displacement at Negative Pole.	Pressure shift per atmosphere.	Pressure necessary to produce displacement.
6102, 6122, 6162 Ca	+ 0·197 A	+ ·024 A	8 2 atmospheres above atmospheric.
5682, 5688 Na	+ 0·36 ? A	+ ·055 A	6·5 atmospheres above atmospheric.
5682, 5688 Na (absorption lines) ...	— 0·019 A	+ ·055 A	0·35 atmospheres below atmospheric.
4531 Cu	+ ·034 A	+ ·009* A	3·8 atmospheres above atmospheric.
		+ ·022† A	1·5 atmospheres above atmospheric.
Fe ur lines	+ ·011 A	+ ·022 A	0·5 atmospheres above atmospheric.
Fe uv lines	— ·012 A	— ·017 A	0·7 atmospheres above atmospheric.

* According to Humphreys. † According to Duffield.

The effect of pressure would be to displace all lines, whereas it has been found that symmetrical lines are not systematically displaced either one way or the other.

The fact of absorption lines at the negative pole having smaller displacement than the emission lines could also be explained as due to lower temperature of the outer regions of the arc, instead of to lower vapour density. The temperature hypothesis does not however explain the other phenomena, for example the displacement due to increase of current density or to shortening the arc.

Ionisation effects may be present in the arc, and in the explanation given above it is not impossible that for the phrase "density of vapour," "density of ions" should be substituted, for in the arc the two

are indistinguishable since practically the whole of the vapour will be ionised. The former is more probably the cause of the displacement, and the point can perhaps be tested in furnace spectra.

There is no difficulty in accounting for a density effect on wavelength. Soon after the announcement of the pressure shift Schuster pointed out the importance of determining whether the shift was dependent on the total pressure or on the proximity of molecules of the same nature.[1] Many observers have tried to detect the effect of the latter but generally with negative results. Exner and Haschek however did find an effect [2] but their conclusions have not gained universal acceptance.[3] The probable reason why negative results have been obtained is that most spectral lines are symmetrical and therefore show no displacement due to density. So far as my experiments go it appears that the displacement of symmetrical lines under pressure is due solely to the total pressure of the surrounding atmosphere, but there is as yet no direct evidence as to whether the displacement of unsymmetrical lines under pressure is due entirely to increased density or partly to the increased total pressure.

The intimate relation between the unsymmetrical character of spectrum lines and their density displacement is of great importance in the theory of the vibrations of elections within the atom and of the mutual influence of molecules due to their proximity. Whatever theory is put forward of the origin of spectrum lines and of their displacements must be able to explain not only the displacements of unsymmetrical lines due to pressure and density to the red or to the violet according as the widening is towards the red or the violet, but also the absence of a density effect on symmetrical lines for which a pressure effect exists.

Consequences of the density effect on other investigations of the displacement of spectrum lines and investigations of wavelength standards.—It is necessary to consider whether the existence of the displacement of unsymmetrical lines by different conditions in the electric arc do not affect the conclusions drawn from the displacements of spectrum lines in other researches in which an electric arc has been employed to produce the spectrum.

The pressure in the reversing layer of the sun can be estimated by comparing the relative sun—arc displacements of the lines most and least affected by pressure. The lines most shifted by pressure, however, are comprised almost entirely of unsymmetrical lines, and since these lines undergo shifts within the arc itself, the sun—arc displacements can be varied at will according to the part of the arc selected for comparison with the sun. It was shown in Kodaikanal Observatory Bulletin No. XXXVIII that even in the centre of very long arc, the conditions producing the shifts in different parts of the arc, whether they be density or not, still do not approach those in the sun. So long, therefore, as the electric arc is used for comparison with the sun, unsymmetrical lines must, for the present, be left out of account altogether in studying the pressure displacement in the sun. Considering only symmetrical lines the pressure in the reversing layer at the level of the iron lines is about three-quarters of an atmosphere [4] and the pressure at the limb is probably not much greater than this.[5]

Also, the arc is the source which has been chiefly employed for the investigation of pressure displacements, and similar considerations will apply. The arc does not always burn well under pressure, and it is a practical impossibility to keep the arc conditions identical with those for the comparison spectrum either as to length or as to the portion of the arc which falls on the spectrograph slit, although this latter in the case of astigmatic spectrographs may not be so important. It will not be surprising, therefore, if the supposed pressure displacement of the unsymmetrical lines does not turn out to be at least partly due to the displacements which occur in different parts of the arc at constant pressure. For instance knowing that the calcium triplet λλ 6102, 6122, 6162, is displaced by 0·198 A at the negative pole compared with the centre of the arc, we cannot ignore the possibility that the shift of these lines under pressure is partly due to this displacement unless it is shown that special precautions have been taken to exclude the polar regions of the arc from entering the spectrograph.

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1 Schuster, Astrophysical Journal, III, 292, 1896

2 Exner and Haschek, Die Spektren der Elemente bei Normalem Druck, Vol. I.

3 See Kayser Handbuch der Spectroscopie, Vol. II, 297, 308, 309, 310 and Eder and Valenta, Astrophysical Journal, XIX, 251, 1904.

4 Royds, Kodaikanal Observatory Bulletin No XXXVIII.

5 Evershed and Royds, Kodaikanal Observatory Bulletin No. XXXIX.

Pressure displacements have also been investigated in the furnace.[1] The same pressure produces much larger shifts in the furnace spectrum than in the arc, and since this is true for symmetrical as well as for unsymmetrical lines, density effects, which do not displace symmetrical lines, fail to account for it. Nevertheless there is a difference between the behaviour of symmetrical and unsymmetrical lines. The following Table VII, compiled from the data of Gale and Adams[2] for the iron arc and of King[3] for the furnace, shows that the ratio of furnace displacement to arc displacement is considerably smaller for the iron lines unsymmetrically widened towards the red, than for symmetrical lines. This fact can be explained if the arc under pressure has been short or the exposure made on a region near the poles, for either of these would cause the shift of the unsymmetrical lines to be larger than the true pressure effect.

TABLE VII.—COMPARISON OF PRESSURE DISPLACEMENTS OF IRON LINES IN FURNACE AND ARC.

Ratio $\dfrac{\text{furnace displacement at 9 atmospheres.}}{\text{arc displacement at 9 atmospheres.}}$

Region.	Symmetrical lines.	Lines unsymmetrical towards the red.
λλ 4063—4461 ...	2·48 (26 lines)	1·49 (5 lines).
λλ 5227—5341 ...	1·97 (7 lines)	1·37 (2 lines).

Although these experiments were not directed to the determination of standards of wavelength they have an obvious bearing on the choice of light source for standard lines. It does not seem necessary to abandon the arc in air so long as symmetrical lines are chosen as standards, but with this source it cannot be expected that independent experimenters will get sufficiently concordant results for unsymmetrical lines on account of the great sensitiveness of these lines to density effects. The arc in vacuo is better for unsymmetrical lines but is not sufficiently convenient for ordinary usage.

What we shall consider as the light source giving "normal" wavelengths for unsymmetrical lines is entirely arbitrary but is of importance when we wish to interpret the displacements in heavenly bodies such as the sun. We have now at least three causes of displacement of spectrum lines:—(1) motion in the line of sight, (2) pressure, and (3) density. It is desirable to eliminate the density shift since we have at present no means of estimating it quantitatively. Whether the arc under reduced pressure or the furnace will prove the more suitable source for comparison with the sun is a matter for investigation.

Test of unsymmetrical character.—The presence of displacements at the negative pole is a simple and powerful means of testing the unsymmetrical character of spectrum lines if we can assume the generality of the rule that only unsymmetrical lines are displaced and these in the direction of their greater widening. In the arc at ordinary pressures the unsymmetrical widening in most cases is not so obvious that its direction is evident; the displacement at the negative pole is, however, generally sufficiently large that the direction of displacement can be at once seen by inspection, although in some cases it would be necessary to measure the displacement. Consider the case of the copper line λ 4578. In the arc at atmospheric pressure this line is so diffuse that it is quite impossible to say whether it is unsymmetrical or not; but supposing that it were important to learn its character for determining its series relationship or other reason, the fact that its displacement at the negative pole amounts to +0·024 A would show that it is unsymmetrical towards the red, but that the dissymmetry is not great in proportion to the width of the line since the copper line λ 4531 comparatively narrow undergoes a larger displacement. This conclusion as to the character of the λ 4578 line is in agreement with that found by Duffield[4] in the arc under pressure.

The method is not so sensitive for lines which reverse at the negative pole since the displacement of the reversal is generally small. As however the unsymmetrical character is in the case of reversed lines easier to detect owing to the reversal not being central, this limitation is not very serious.

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[1] King, Astrophysical Journal XXXIV, 37, 1911; XXXV, 183, 1912.
[2] Gale and Adams, Astrophysical Journal XXXV, 10, 1912.
[3] King, Astrophysical Journal XXXIV, 37, 1911.
[4] Duffield, Phil. Trans. Roy. Soc. A. 209, 205, 1908.

SUMMARY.

1. When the spectrum of the region of the arc near the negative pole is compared with that of the centre, the unsymmetrical lines are seen to be displaced in the direction of their greater widening; *i.e.*, lines widened more towards the red are displaced to the red at the negative pole, and those widened more towards the violet are displaced to the violet. Symmetrical lines have very small displacements if they are really displaced at all. The displacement amounts to over one-tenth of an Angstrom unit for 18 lines examined, a number which could probably be easily multiplied by extending the investigation to other elements and regions of the spectrum. The largest displacement yet measured is 0·52 A. for the sodium pair λλ 6154, 6160.

2. There is a displacement in the region near the positive pole of about half the magnitude of that at the negative pole.

3. A displacement of the same sense as that at the poles is produced at the centre of the arc by increasing the current, or by shortening the arc.

4. The displacement at the negative pole is reduced if only the positive pole is supplied with the material producing the spectrum.

5. Displacements occur in the arc in vacuo also, but to a much smaller extent than in the arc in air. The arc in vacuo is therefore the better source for the determination of standards of wavelength and for comparison with the sun's spectrum.

6. When a line reverses in the region near the negative pole the displacement of the reversal is much smaller than that of the unreversed line, but is generally in the same direction; in the case of very unsymmetrical lines such as the sodium pair λλ 5682, 5688, the displacement of the absorption line is in the opposite direction relative to the line at the centre of the arc.

7. The cause of the displacement is shown to be increase of vapour density of the material producing the spectrum. The pressure required to produce the displacements observed is too large to be entertained as existing in the arc in air and other possible hypotheses have also to be rejected.

8. The vapour density in the sun's reversing layer is lower than that at the centre of the arc under the conditions of my experiments.

9. The intimate relation between the unsymmetrical widening and the displacements due to increased density or to pressure, as well as the absence of any density effect on symmetrical lines for which a pressure effect exists, are believed to be of importance in the theory of these shifts and of the vibrations of the electrons in the atom.

10. The possibility of displacement at the negative pole seems to be a simple and effective means of testing the unsymmetrical character of spectrum lines, since no exceptions have been found (in unreversed lines) to the generality of the rule that unsymmetrical lines are displaced in the direction of their greater widening.

11. The bearing of the density effect on some other investigations of displacements in which the arc has been used is discussed.

I wish to acknowledge my indebtedness to Messrs. S. Sitarama Ayyar, G. Nagaraja Ayyar and A. A. Narayana Ayyar, the first, second and third assistants respectively, for valuable assistance in measuring the photographs.

KODAIKANAL OBSERVATORY,
August 6th, 1914.

T. ROYDS,
Assistant Director.

MADRAS: PRINTED BY THE SUPERINTENDENT, GOVERNMENT PRESS.

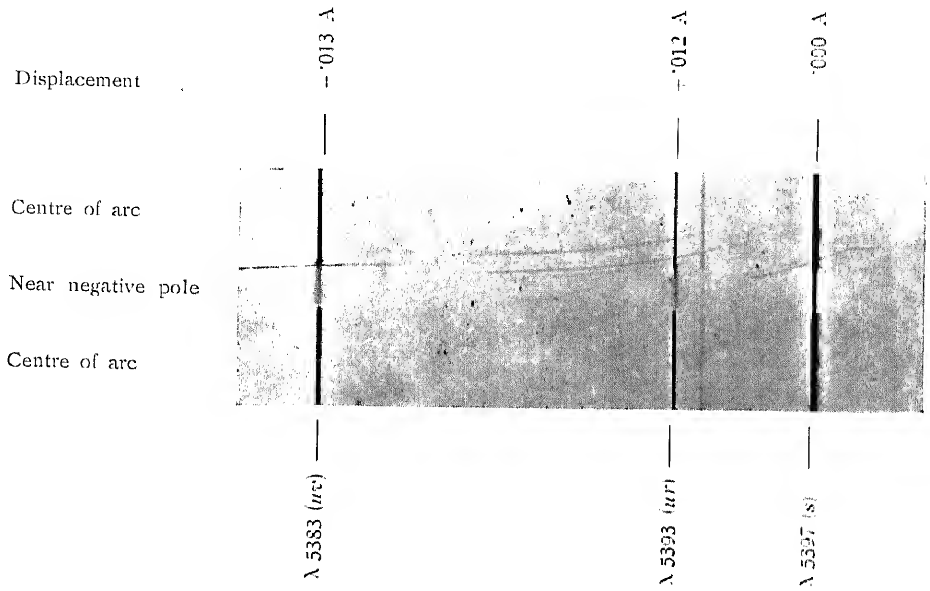


Fig. 1.—IRON LINES.

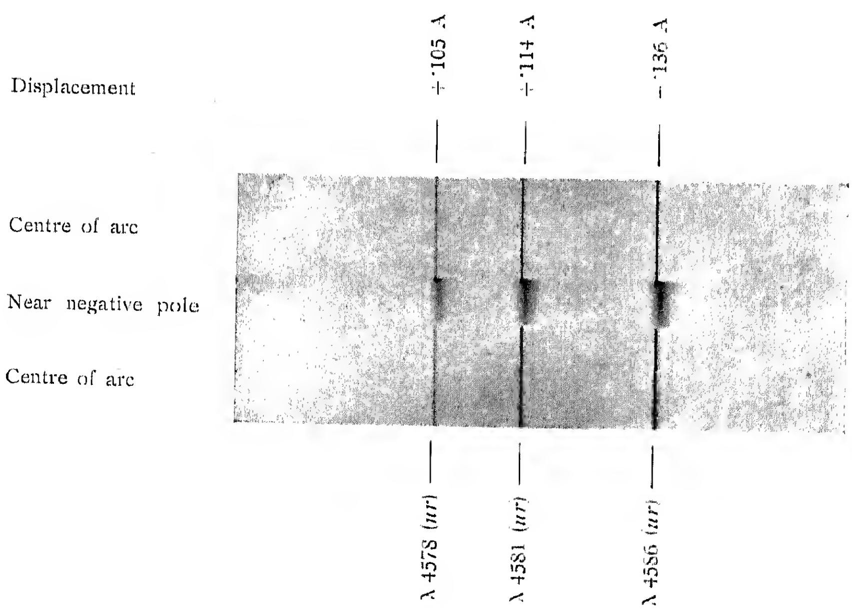


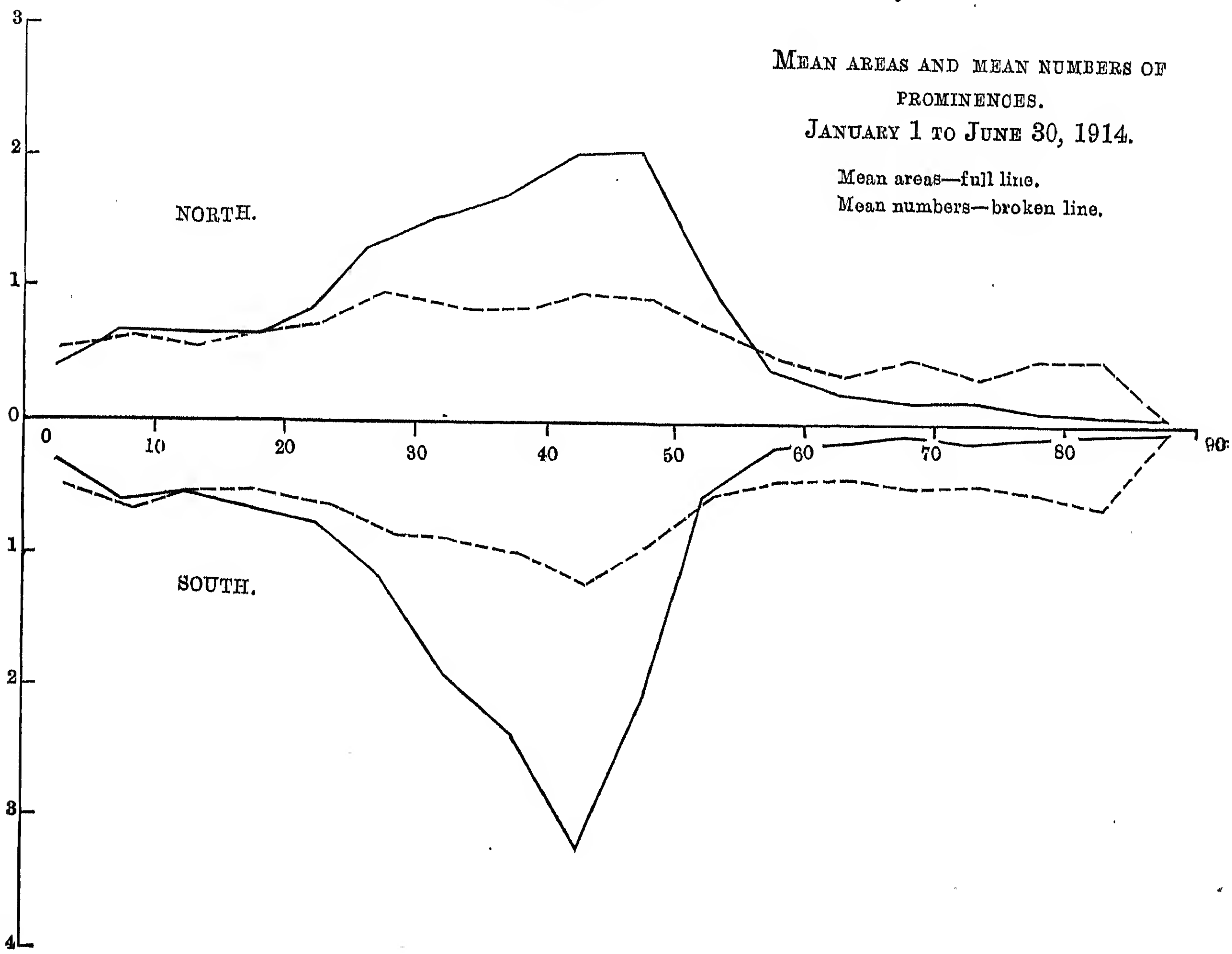
Fig. 2.—CALCIUM TRIPLET near λ 4580.

Kodaikanal Observatory.

BULLETIN No. XLI.

SUMMARY OF PROMINENCE OBSERVATIONS FOR THE FIRST HALF OF THE YEAR 1914.

The distribution in latitude of the prominences observed during[the six months ending June 30, 1914, is represented in the accompanying diagram. The full line gives the mean daily areas, and the broken line the mean daily numbers for each zone of 5° of latitude. The ordinates represent tenths of square minutes of arc for the full line and numbers for the broken line. The means are corrected for partial or imperfect observations, the total of 175 days being reduced to 158 effective days.



The mean daily areas and daily numbers for each hemisphere corrected for partial observations are as follows :—

	Areas. Square minutes.	Numbers.
North	1·44	11·10
South	1·49	11·08
Total ...	2·93	22·18

There was a distinct recovery of prominence activity during the period. Both areas and numbers show an increase compared with the year 1913, the areas being about 20 *per cent.* and the numbers 15 *per cent.* greater than the corresponding figures for the first half of 1913. The increase affects practically all latitudes up to 60° north and 60° south and has even slightly affected the quiescent polar regions. The distribution in latitude was very much the same as in the previous six months but the northern maximum in the zone 40° to 50° was very much more pronounced in 1914.

The striking feature in the area curve in the southern hemisphere is the very conspicuous peak in the region 40° to 45° falling steeply on the pole side and somewhat more gently towards the equator.

The monthly, quarterly, and half-yearly frequencies and the mean height and extent are given in the following table. The frequencies given are corrected for partial observations.

Abstract for the first half of 1914.

Months.	Number of days of observation.		Number of prominences.	Mean daily frequency.	Mean height.	Mean extent.
	Total.	Effective.				
					″	°
January	31	28	679	24·2	23·7	1·20
February	28	27	648	24·0	26·1	1·12
March	31	29	653	22·5	26·5	0·90
April	30	29	701	24·2	26·5	1·04
May	29	26	491	18·8	29·5	1·42
June	26	19	342	18·0	28·8	1·48
First quarter	90	84	1,980	23·6	25·4	1·07
Second quarter	85	74	1,534	20·7	28·0	1·26
First half-year	175	158	3,514	22·2	26·5	1·15

The increase of frequency and of area during the 6 months compared with 1913 is slightly discounted by a reduction in mean height, viz. from 29″·2 in the corresponding period of 1913 to 26″·5 in 1914. The mean extent is sensibly the same as in 1913.

The number of prominences 60″ or more in height was also smaller, being only 295 as against 334 in the first-half of 1913. The average was 1·9 *per diem*. The general reduction in height was also evident by the relatively small number of very tall prominences; only 3 prominences were recorded reaching a height of 180″ as against five exceeding 180″ in the first-half of 1913.

Distribution east and west of the sun's axis.

The period under consideration shows a preponderance on the western side, particularly in the case of the areas. The numbers show an eastern preponderance in the first three months and a western in the second three. The distribution was as follows :—

1914 January to June.	East.	West.	Percentage east.
Numbers observed	1,789	1,775	49·49
Total areas in square minutes of arc ...	220·0	243·4	47·47

Metallic prominences.

Five only were recorded during the 6 months, particulars of these are given in the following table :—

Date.	Time. I.S.T.	Base.	Latitude.		Limb.	Height.	Elements giving bright lines.
			North.	South.			
1914.	H. M.	°	°	°		″	
January 10 ...	9 42	...	...	11	E	...	D_1, D_2, b_1, b_2, b_3. No prominence but chromosphere very bright over about 1°.
„ 17 ...	8 56	2	...	68·5	W	15	D_1, D_2, b_1, b_2, b_3.
April 6 ...	8 38	1	...	45	W	65	b_1, b_2, b_4.
„ 12 ...	9 28	1	24·5	...	W	30	D_1, D_2, b_1, b_2, b_3, b_4.
„ 12 ...	8 58	1	30	...	W	15	D_1, D_2, b_1, b_2, b_3, b_4.

The last two were associated with the very active spot group in latitude 28° N., longitude 72°.

Displacements of the hydrogen lines.

The general increase of activity in 1914 is shown by the displacements of the C line of which 144 have been recorded as against 87 in the corresponding period of 1913.

Particulars of these disturbances are given in the following table :—

DISPLACEMENTS OF C LINE IN PROMINENCES—JANUARY TO JUNE 1914.

Date.	Time. I.S.T.	Latitude.		Limb.	Amount of displacement.			Remarks.
		North.	South.		Red.	Violet.	Both ways.	
1914.	H. M.	°	°		A	A	A	
January 4 ...	8 43	...	86·5	E		Slight.		
„ 6 ...	9 54	...	12	E	Slight.			
„ 9 ...	9 22	...	80	W	Slight.			
„ 10 ...	9 49	...	67·5	W	1			
„ 11 ...	8 52	...	85	E		0·5		Not seen at 9h 58m.
„ 12 ...	9 53	...	84·5	E		Slight.		
„ „ ...	9 41	...	84·5	W	1			
„ „ ...	9 41	...	84	W	Slight.			Not seen at 9h 20m.
„ „ ...	9 20	...	84	W		Slight.		Not seen at 9h 41m.
„ 13 ...	10 10	62·5	...	E		Slight.		
„ „ ...	9 18	...	22	W	1			
„ 5 ...	9 33	43	...	E	1			
„ „ ...	9 53	...	71·5	E	Slight.			
„ „ ...	9 55	...	80	E	Slight.			
„ „ ..	8 58	70·5	...	W			Slight.	
„ „ ...	8 57	78	...	W		Slight.		
„ 16 ...	8 45	...	83·5	E	2			
„ 17 ...	8 56	...	68·5	W	1			
„ „ ...	9 7	...	68·5	W		5		The displacements were in two different places over the prominence.
„ „ ...	...	...	68·5	W	1			
„ 18 ...	9 21	...	72·5	W	1			
„ „ ...	9 3	55·5	...	W		Slight.		
„ 20 ...	9 21	...	28	W	1			
„ 21 ...	9 16	43	...	E		Slight.		
„ „ ..	9 29	...	26·5	E		Slight.		
„ „ ...	8 38	83	...	W		Slight.		
„ „ ...	8 38	84		W		Slight.		
„ 23 ...	9 37	...	57·5	E		1		
„ 24 ...	10 5	...	68·5	E	Slight.			
„ „ ...	8 41	...	77·5	E	0·5			
„ „ ..	9 55	...	79·5	W		0·5		
„ „ ...	9 52	...	74	W			Slight.	
„ „ ...	9 33	57·5	...	W			Slight.	
„ 26 ...	9 0	67·5	...	E	0·5			
„ 27 ...	9 6	84	...	E		Slight.		
„ „ ...	8 31	...	43·5	E		Slight.		
„ „ ...	8 30	...	49·5	E		Slight.		
„ „ ...	8 26	...	69·5	E		Slight.		
„ 28 ...	9 29	...	73·5	W	1			

DISPLACEMENTS OF C LINE IN PROMINENCES—JANUARY TO JUNE 1914—*cont.*

Date.	Time, I.S.T.		Latitude.		Limb.	Amount of displacement.			Remarks.
	H.	M.	North.	South.		Red.	Violet.	Both ways.	
1914.			°	°		A	A	A	
January 28	8	52	...	64·5	W		Slight.		Shifts at different parts of the prominence.
„ „	8	52	...	64·5	W	Slight.			
„ „	9	20	...	29	W		1		Not seen at 9h 16m.
„ „	9	20	...	29	W	1			
„ 30	9	2	84	...	E		Slight.		
„ „	8	38	...	63·5	E	1			
„ „	9	12	...	82	W			Slight.	
„ „	9	16	...	64·5	W	Slight.			
„ „	9	22	...	80	W		Slight.		
„ 31	8	52	64·5	...	E	Slight.			
„ „	9	38	...	47·5	E	0·5			
„ „	9	41	...	68·5	E		Slight.		
February 1	8	28	...	28·5	E			Slight.	
„ „	8	13	...	83	W		Slight.		
„ „	8	12	...	78·5	W	Slight.			
„ 3	10	10	...	12	E	Slight.			
„ „	10	18	...	78·5	E	Slight.			
„ „	10	22	...	82	E		0·5		
„ „	9	8	...	83·5	W		Slight.		
„ 4	8	40	...	84	W	Slight.			
„ 6	8	42	83	...	E	Slight.			
„ 8	8	22	...	57	W		Slight.		
„ „	9	0	...	11·5	W		1		Not seen at 9h 8m.
„ „	9	0	...	11·5	W	3			
„ 11	8	24	...	58·5	W	Slight.			
„ 13	9	4	83	...	E	Slight.			
„ „	8	38	...	81·5	W		1		
„ 16	9	33	Equator.		E			Slight.	Slightly bulged out both ways.
„ 20	8	57	81	...	E		2		
„ „	8	31	...	78	W	1			
„ 21	8	13	80	...	E			Slight.	
„ „	8	4	70	...	E		1		Disappeared in a few seconds.
„ „	8	5	61	...	E	Slight.			
„ „	8	19	45·5	...	W	Slight.			
„ 22	8	40	62	...	E	Slight.			
„ „	9	26	...	41·5	W		Slight.		
„ 23	9	30	...	78·5	W		0·5		
„ „	10	0	...	70·5	W			Slight.	
„ 25	8	39	78	...	E	0·5			
„ „	8	34	71·5	...	E	Slight.			
„ „	8	29	50	...	E			Slight.	C was symmetrically widened in the chromosphere to the north of this prominence.
„ „	8	52	...	77	E	0·2			Shift found over the whole prominence.
„ 26	8	44	...	79·5	E		Slight.		
March 2	9	16	49	...	E		Slight.		
„ „	8	58	...	81·5	W		Slight.		
„ „	8	58	...	32	W	2·5			
„ „	9	26	75·5	...	W		Slight.		
„ 5	9	41	79·5	...	E		2		Shift gradually increased, but disappeared at 9h 45m.
„ „	8	41	...	56	E		0·2		
„ „	8	33	...	77·5	W	0·2			
„ „	9	9	78	...	W			Slight.	Not seen at 9h 49m.
„ 8	9	7	...	75·5	W	0·5			
„ „	8	36	70	...	W		Slight.		
„ 9	9	2	...	75·5	W		0·5		
„ 12	8	28	...	67	W		Slight.		
„ 14	8	34	...	74·5	E	1·0			Displacement at top of prominence.
						0·5			Displacement at base of prominence.
„ „	8	33	...	75·5	E		1·5		Disappeared in a few seconds.
„ 15	8	45	...	15	W	Slight.			
„ 17	8	55	18	...	E		1·5		
„ „	8	57	18	...	E	0·5			
„ 19	8	19	49·5	...	W	0·5			
„ 22	8	53	81·5	...	E			Slight.	
„ „	8	39	68	...	W		1		At top of prominence.

DISPLACEMENTS OF C LINE IN PROMINENCES—JANUARY TO JUNE 1914—*cont.*

Date.	Time. I.S.T.		Latitude.		Limb.	Amount of displacement.			Remarks.
			North.	South.		Red.	Violet.	Both ways.	
1914.	H.	M.	°	°		A	A	A	
March 22	8	39	68	...	W	0·5			At base of prominence.
,, 27	8	44	...	62	E	0·5			
,, ,,	8	48	...	73·5	W		Slight.		
,, ,,	9	9	...	28	W	1			
,, ,,	9	7	21	...	W			Slight.	
,, ,,	8	58	78	...	W	Slight.			
,, 28	9	30	73	...	W		1		At top of prominence.
,, 30	8	38	26	...	E		1		C displaced to red in many places near this position at 9h 52m.
,, ,,	8	38	26	...	E	1·5			
April 1	8	41	41·5	...	E		0·5		
,, ,,	9	15	...	54·5	W	Slight.			
,, 6	8	38	...	45	W		1		At base of prominence. Disappeared at 8h 55m.
,, 12	9	28	24·5	...	W			0·5	
,, ,,	9	2	30	..	W		3		Not seen at 9h 5m but was seen at 9h 44m when the amount of displacement was 1·0 Å.
,, 13	8	22	57·5	...	E	Slight.			
,, 15	9	14	71·5	...	E		Slight.		
,, ,,	8	35	...	41	E			Slight.	
,, ,,	8	54	...	58·5	W	2·5			Not seen at 8h 57m.
,, 16	8	54	31	...	E	0 5			There appeared to be a mass of dark hydrogen in front of the prominence obscuring the central part of it.
,, 17	8	37	80·5	...	E	Slight.			
,, 19	8	33	...	2	E	Slight.			
,, ,,	8	26	...	83	E		Slight.		
,, 22	8	48	30·5	...	E		0·5		At base of prominence.
,, ,,	8	25	...	32	E		Slight.		
,, ,,	9	2	...	28	W			Slight.	
,, 25	8	21	...	74·5	E		0·5		
,, ,,	8	14	...	41	W		0·5		
,, 26	8	59	...	22	W		1		Over whole prominence.
,, 29	9	20	26	...	E	Slight.			
,, ,,	9	26	...	42	E	...	Slight.		
May 1	8	36	...	54	E		0·5		
,, ,,	8	30	...	79·5	W		1		
,, 10	8	28	68	...	E	0·5			
,, ,,	7	57	...	81·5	W		0·5		
,, 12	8	51	...	63	W		Slight.		
,, ,,	8	26	...	45	W		1		
,, 25	8	25	51·5	...	E	Slight.			
June 2	9	24	17	...	E			Slight.	Bulged out slightly both ways.
,, 13	9	33	75·5	...	E	Slight.			
,, 17	8	35	29	...	W			Slight.	
,, ,,	8	30	63	...	W		1		At top of prominence.
,, 28	8	43	70	...	E		Slight.		

As is usually the case, at any rate at times of sunspot minima, the largest number was found in high latitudes between 60° and the poles where 85 were observed; 31 were recorded in mid-latitudes between 30° and 60°, and 28 in low latitudes between the equator and 30°. Sixty per cent. of these disturbances were in the southern hemisphere.

The distribution east and west of the sun's axis shows a slight preponderance on the west side, the figures being 71 east and 73 west, a proportion which is the same as that found for the prominences.

There is a preponderance of displacements towards violet in this series of observations, 66 being displacements towards violet, 61 towards red, and 17 in both directions simultaneously.

The greatest displacement recorded was 5 angstroms towards violet on January 17 in a prominence at latitude — 68° W. This prominence was not visible at 8^h 52^m I.S.T., but was very bright at 9^h 02^m showing

the sodium and magnesium lines bright, it rapidly increased in height from 35″ at $9^h\ 02^m$ to 140″ at $9^h\ 22^m$ at $9^h\ 50^m$ it had disappeared. The displaced portion of the line was entirely detached from the undisplaced line.

Reversals and displacements of the C line on the disk.

Forty-seven reversals of the C line were observed in the neighbourhood of sunspots. These also curiously enough show a preponderance west of the central meridian, 29 being west and 18 east. Thirty-eight displacements were recorded, of which 20 were east of the central meridian. Twenty-four displacements were towards the red and only 11 towards violet and 3 in both directions simultaneously.

The spots of March 31 to April 12, latitude + 28°, and April 27 to May 3, latitude + 18°, were especially active in producing reversals and displacements of the hydrogen lines.

Prominences projected on the disk as absorption markings.

Owing to the use of the large Michelson grating for other work no photographs of the sun's disk in H*a* light were obtained. A new grating has been ordered and it is hoped to continue the records when this has been received.

A very conspicuous absorption marking was photographed in calcium light on five days from April 9 to April 13 inclusive. It was in latitude + 45° to + 54° and crossed the central meridian on April 13.

THE OBSERVATORY, KODAIKANAL,
15th August 1914.

J. EVERSHED,
Director, Kodaikanal and Madras Observatories.

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Kodaikanal Observatory.

BULLETIN No. XLII.

REPORT ON THE CONDITIONS FOR ASTRONOMICAL WORK IN KASHMIR.

It has been the universal experience at all mountain observatories, and perhaps to a less extent at observatories situated near sea-level, that the best time of day for steadiness of seeing for the sun is during the first few hours after sunrise, when the atmosphere is cool and calm. Later in the day the definition becomes so bad from unequal heating of the air and local ascending currents of heated air that all photographic work is usually suspended, and it is very rarely possible to follow up the interesting changes that may be going on in sunspots or in prominences from hour to hour. Spectroscopic and spectrographic work, which is now of supreme importance in the study of the sun is even more seriously hindered by these adverse conditions.

During a visit to the Valley of Kashmir in August and in October 1913 the observing conditions for solar work were found to be extraordinarily good. Contrary to all previous experience in other localities, the definition of the sun was found to be of the best quality throughout the day and on all the days that observations were made, there being apparently no marked variations depending on the height of the sun above the horizon, nor upon the type of weather prevailing. From the first hour after sunrise to the last before sunset photographic and spectrographic work of the highest excellence would have been possible. The higher valleys were visited in September, ascending to about 12,000 feet, but the definition was found to be not so good as in the main Valley.

It may here be explained that the Valley of Kashmir is a nearly level plain extending for about 80 miles in a north-west and south-east direction, with many smaller side-valleys opening into it from the surrounding mountains. It is about 15 to 20 miles in width and is completely enclosed by high mountains. The Pir Panjal chain of peaks on the south-west side rises to 15,000 feet above sea-level, whilst the mountains on the north and north-east side exceed 20,000 feet in some cases. In spring and early summer a complete ring of snow-covered peaks is visible from the centre of the valley. The plain is elevated above sea-level 5,200 feet at Srinagar. The alluvial soil is highly cultivated, and there are numerous water-ways and irrigation channels as well as the broad and placid Jhelum river flowing through it. The plain appears to have been the bed of a lake, and there are still large masses of water near the north-west end, such as Wular Lake and the Dal and Anchar lakes. Owing to the protection afforded by the surrounding mountains the air within the valley is extraordinarily tranquil, and high winds are very exceptional.

Observations made with a telescope or field-glass of terrestrial objects such as distant mountain peaks indicated by the remarkable clearness of vision the unusual tranquillity of the air, and small objects from 50 to 100 miles distant could be examined with a powerful astronomical telescope with very little interference from atmospheric tremors. The observations of the sun appeared to show that the Valley of Kashmir might offer very exceptional opportunities for solar research, if the conditions found in August and October were fairly representative of the whole year.

With a view to testing the conditions during other months of the year, and also to make more critical observations with larger instruments, an expedition to Kashmir was sanctioned by Government in April 1914, and the result of the work done during this expedition is the subject of this Report.

Before starting for Kashmir, the following scheme of operations was arranged:—

(1) A series of photographs of the sun was to be taken at Kodaikanal during March and April with a 3-inch photoheliograph specially arranged for the work. The instrument was then to be transported to Kashmir, and a second series of photographs taken under identical instrumental conditions. The definition of the photographs obtained would give a good comparison of the average "seeing" at the two stations.

(2) Critical observations of the definition of the sun were to be made with a 4½-inch visual telescope at different hours of the day and on as many days as possible while in Kashmir.

(3) Sunspot spectra and prominences were to be observed with a grating spectroscope, whenever possible, in order to see how such observations would compare with those habitually made at Kodaikanal.

(4) It was planned to test the definition of stars and planets with the 4½-inch telescope.

(5) It was considered desirable to spend part of the time in touring in the Kashmir Valley and neighbouring hills, to discover the limits of the good conditions which prevail, and to test the influence of different local conditions on the seeing.

Instrumental Outfit.—The principal instruments taken to Kashmir include the following:—

(1) A 3-inch photoheliograph constructed for the work at Kodaikanal.

(2) A polar heliostat adapted for use with the photoheliograph.

(3) A 4½-inch equatorial telescope by Grubb, kindly loaned by Dr. Walker.

(4) A grating spectroscope for use with the 4½-inch telescope.

(5) A 3-inch portable telescope.

ITINERARY.

The personnel of the expedition consisted of the writer, Mrs. Evershed, and one servant. Mrs. Evershed had had considerable experience of the kind of work in New Zealand, where she had become expert in estimating the quality of the seeing by projecting the sun's image on a screen. Endeavours were made to secure the services of a photographic assistant in Srinagar, but no one qualified for the work could be obtained.

The expedition reached Srinagar on May 3, and observations of the sun were begun with the portable telescope on May 4. The heavier instruments were not received until May 7. While making the necessary arrangements in Srinagar we received valuable help from the Assistant-Resident, Major James, from Rai Bahadur Dr. Mitra, Home Minister for Kashmir, from the Governor of the State, who provided us with a general order to all officials of the districts to be visited to render every assistance, and from the Motamid Durbar. Dr. Arthur Neve of the Mission Hospital, Srinagar, also gave valuable advice.

A doonga was hired, and all instruments and stores put aboard, and on May 11 we started on a prospecting tour up the River Jhelum as far as Islamabad, observing the sun from the river bank at various localities. A very convenient site for a temporary Observatory was found about 10 miles out from Srinagar near the village of Pampur. This was a small grass-covered hillock about 100 yards from the river bank, rising some 20 feet above the general level of the plain. On this, most conveniently arranged for our work, were some foundations of an abandoned building with stone walls about 3 feet high, and plenty of building materials lying near. A very small amount of masonry work was needed to adapt these walls for mounting the polar heliostat, which had to be raised above the ground about 7 feet in order to reflect the sun downwards at the correct angle.

The photoheliograph was fixed on a heavy plank built into the wall, and a 10 by 10 feet tent was pitched over it. A small dark room was built adjoining the tent for developing plates, etc. Another tent was pitched near and adapted for use as an Observatory, the 4½-inch telescope being mounted inside. By unlacing a portion of the tent the tube of the telescope could be directed to the sun through the opening, and observations made inside the tent. The most satisfactory method was to project a large image of the sun from 2 to 3 feet diameter on to a white screen placed in the semi-darkness of the tent. Spectroscopic observations could also be made in the tent. The views of the solar surface obtained in this way were very remarkable. Minute spots or pores which were estimated at ½″ to 1″ of arc in diameter could be clearly seen and the rapid changes studied from hour to hour, whilst sunspots of any considerable size were magnificent objects.

The telescope was erected on May 18, and detailed visual work was started on that day. A continuous record of the state of the seeing had however been made from May 4 with the 3-inch portable telescope. The photoheliograph was in operation on May 22, and numerous photographs were obtained with it until June 3. On that day the camera and plate holder were dismounted and modified in such a way that they could be attached to the 4½-inch telescope, in order to obtain photographs of portions of the solar disc, including sunspots, on a very much larger scale than was possible with the photoheliograph. The performance of the 4½-inch telescope on the sun was so good that it appeared worth while to attempt photography with this telescope notwithstanding the fact that the colour-correction of the object-glass was for the visual rays. The photographs with this instrument would be comparable with those taken on the same days at Kodaikanal with the 6-inch photo-visual telescope, although the theoretical resolving power is less in proportion to the diameter of its object glass.

To adapt the visual telescope for photography, the component lenses of the object-glass were separated about 3 mm. to achromatize the rays more perfectly between G and F of the spectrum. It was then necessary to limit the light affecting the photographic plate to the spectral region between G and F, that is to cut out the whole of the violet and ultra-violet, which would not be perfectly focussed. This was accomplished by the use of two coloured absorbing screens of optically worked glass, a deep green and a yellow. An ordinary eye-piece of considerable power was used to project a large image on the plate, which was placed in a whole-plate slide attached to the end of the camera-box which fitted to the draw-tube of the telescope. A Kodak exposing shutter taken from a pocket camera was attached inside the camera-box and immediately behind the eye-piece; this was set to give the shortest exposure or 1/100 of a second. The rubber tube of the pneumatic release passed through a hole in the camera-box so that the bulb was accessible from outside. The small finder telescope attached to the equatorial was used to project an image of the sun on a marked screen in order to determine exactly when the sunspot to be photographed was central in the camera. It was a matter of no small difficulty with a telescope unprovided with clock driving to hit off the exact moment for making the exposure and at the same time avoid disturbances due to the wind shaking the telescope.

With this apparatus, notwithstanding the difficulties of manipulation, a very good series of photographs was obtained of a fine spot-group visible between June 7 and 21, using Imperial "Lantern" plates.

On June 20, having obtained a satisfactory series of visual and photographic observations, both of the day and night definition, the Observatory camp was placed in charge of the official chowkidhar of the village of Tengan, and we started on a tour to various localities to test the influence of local conditions on the definition of the sun. During this tour observations with the 3-inch portable telescope were made at a large number of stations in the valley and in the mountains, the route chosen being from Awantipur on the Jhelum river to Traal, and thence over the Bugmar pass to the Lidar valley, ascending this to an altitude of 11,000 feet at Zojpal. Returning from the high elevations, the Jhelum river was reached again at Bijbihara and the journey continued by river to near Awantipur and thence by two marches across the valley to the foothills of the Pir Panjal range near Romu. These last marches gave us an opportunity of testing the definition in the midst of vast stretches of wet rice cultivation, and also on low hills of about 200 feet elevation above the general level of the valley. From Romu the plain was re-crossed diagonally back to Pampur, the observing camp being reached on July 8. After a few further observations with the 4½-inch telescope the whole equipment was packed and transferred to the doonga, and the expedition reached Srinagar on July 13.

After arranging for the transport of the heavy baggage to Rawalpindi, a further set of observations was made with the 3-inch telescope across the level plain to the north-west of Srinagar and up the hills to Gulmarg. Here a stay of two days was made and the Assistant Resident and the Home Minister were again visited. On this visit to Gulmarg we were accompanied by Professor Chowla of the Government College, Lahore, who was on a holiday tour in Kashmir and who kindly assisted us in many ways.

The programme of work being completed, we started on July 19 on the return journey to Kodaikanal. Madras was reached on July 25, and a few days were spent in inspecting the observatory, Kodaikanal being reached on July 30.

Observations with the 3-inch portable telescope were continued after arrival for some weeks in order to estimate the solar definition by the same method as had been adopted in Kashmir.

RESULTS.

It may be stated at once that the remarkably favourable conditions discovered in 1913 in August and October have been found to be maintained also during the months of May, June and July, and there is no reason to doubt that the remaining months of the year, especially September and November, will also prove favourable. Owing to the prevalence of cloud during the winter, observations in December, January and February would be limited in number, although in all probability exceedingly good in quality.

The quality of the seeing was estimated by adopting a rough scale of five figures, in which 1 denotes very bad definition, 2 bad, 3 fairly good, 4 good, and 5 so perfect that no tremors can be perceived in the 8-inch solar image projected on the screen attached to the portable telescope. Seeing 1 and 2 would be useless for photographic work, except of the roughest kind for determining approximate spot positions. It was found in practice that fractions between the units could be discriminated and a scale of 10 units would perhaps have been more convenient.

During the 61 days spent in the valley of Kashmir, 204 estimates of the seeing were made, and the mean of all is 3·9. The observations were made at all hours of the day, and dividing them into three periods, morning, midday, and evening, the following interesting result is obtained.

Between 6 A.M. and 11 A.M. average seeing	3·8
„ 11 A.M. and 3 P.M. „	4·2
„ 3 P.M. and 6·30 P.M. „	3·9

The better quality of seeing at midday or a little after noon had often been noticed when working with the 4½-inch telescope, and it appeared as if the best definition, often classed as 5 when estimating with the smaller telescope, occurred between 2 and 3 P.M. As the morning observations were more numerous than those taken at midday or in the afternoon, the general mean is lower than it would have been had the observations been evenly distributed through the day.

Another remarkable feature is the constancy of the good seeing from day to day. This is in marked contrast to our experience at Kodaikanal, where the variations are erratic and often occur without any apparent change in the type of weather prevailing.

In the Kashmir Valley the worst seeing recorded was 2, and this occurred on only three days: one of these was an observation made during a temporary break on a very wet day; another was near sunset at 6-30 P.M. On the third occasion the day was fine, with seeing estimated at 2 during the morning, improving to 3 in the afternoon. This was the only fine day on which the seeing was not altogether satisfactory: on all fine days it ranged from 3 to 5 according to the time of day, and also to some extent according to the locality, for it was found that the very finest seeing was obtained when the telescope was located near large areas of wet cultivation, as near the entrance to the Lidar valley or near Romu, or on some small islands on the Dal lakes near Srinagar.

These islands were visited on June 13, and from the Sona Lankh in the Bod Dal the seeing was estimated as from 4½ to 5 continuously between 11 A.M. and 3 P.M. From this island the water surface is practically continuous for about 3½ miles to the south or south-east, and there are many water channels and marshes to the south-west. No doubt this fact contributed to the good seeing, because of the absence of disturbances in the lower strata of the air by contact with the sun-heated soil or rock surface.

It was found that no particular advantage was gained by ascending the low flat-topped hills called karewahs that stretch out into the plain from either side of the valley. The definition here seemed slightly less good than on the level plain among the rice fields. On the Takht-i-Suleiman hill, which rises a thousand feet above the plain, the best seeing was estimated at 4½ and the worst at 3 during a morning, and there appeared to be a tendency toward poorer seeing as the sun rose higher in the sky, as seems to be always the case on mountain tops.

In the Lidar Valley, which opens out on the main valley on its north-east side, 46 observations of definition were made. In the lower and wide part of this valley at about 6,000 feet above sea-level the [illegible] the same as in the main valley: here also there is much wet cultivation, and the

country is intersected with irrigation channels. At higher elevations up to 11,000 feet at Zojpal the valley becomes very much narrower, with steep rocky sides and much snow on the higher slopes. Here the seeing was decidedly less good, although the average for all the observations taken in the Lidar Valley is as high as 3·4.

At Gulmarg at an elevation of 8,800 feet in the Pir Panjal range on the south-west side of the main valley, observations were much impeded by cloud, but in the clear hours the definition was found to be distinctly inferior to that in the valley. The general result of our experience at high elevations in the mountain ranges on either side of the main valley tends to show that, while the conditions are good over the whole region traversed, local air currents set up in the high valleys among steep inclines with more or less bare rock surfaces injure the quality of the solar definition to a marked degree; and in addition to this there is a much greater tendency to cloud and mist among the hills than in the level plain. At night the definition of stars was generally exceedingly good at the higher elevations, but was not so constantly good as appeared to be the case in the valley.

The night definition of stars, etc., was studied at Pampur and at other places in the main Kashmir Valley. With the 3-inch telescope it appeared to be perfect when the star's zenith distance did not exceed 60° on all occasions but one. With the 4½-inch equatorial telescope star-images were usually perfect at zenith distances up to 50° or 60°, the diffraction pattern appearing like an engraving and sliding with an absolutely uniform movement across the field of view (the telescope was not provided with clock driving for following the diurnal movement). A very slight undulation was on some nights perceptible, and at low elevations below 20° altitude slow and regular undulations were always visible. The definition of the planet Jupiter was nevertheless very fine when only about 10° to 15° above the horizon, the undulations being of such a nature as not to interfere very seriously with the visibility of fine details on his surface. These slow undulations were also always present when observing the sun during the first hour after rising or the last hour before setting.

As regards the cloudiness in the main valley, our observations at Pampur, Srinagar, and other places show that 50 out of the 61 days spent in the valley were clear sunny days, 7 were partially clear, and 4 completely overcast. Since the partially fine days were available for photographing for at least one hour in each day, there were 57 days, or 93 per cent. of the days in which excellent photographs could be obtained. Twenty-five of the 50 fine days were practically without cloud from sunrise to sunset. As a rule the sky was beautifully clear and of a deep blue colour, but there was a tendency to the formation of high cirrus clouds towards afternoon; also on two occasions in June observations were very much impeded by thick dust haze from the Punjab. This latter was the worst type of weather experienced from an astronomical point of view, but it was fortunately of short duration.

Comparison of Results at Kodaikanal and in Kashmir.

At Kodaikanal the seeing was estimated with the same telescope and by the same method as was used in Kashmir, immediately after returning to head-quarters. There was a great deal of interruption from cloud owing to the prevalence of the south-west monsoon, and the seeing varied a good deal from day to day, ranging from 1 to 3, the mean for the month during the hour between 7-30 and 8-30 A.M. being 2·1. In the middle of the day on two occasions when it was possible to see the sun it was no better than 1. It must be remembered that the six months May to October inclusive are generally unfavourable at Kodaikanal, July and August being the worst months when good definition is unusual even at 8 A.M. During the other half of the year it would be better, and might be estimated at 3 to 4 at 8 A.M., rarely reaching 5 After 8-30 A.M. the definition falls off rapidly, so that the mean for the whole day, even at the best season of the year, would not exceed 2.

So far as is possible therefore to estimate numerically the definition at the two stations, it may be stated approximately that the mean seeing at Kodaikanal for the whole year would hardly reach 2, whilst that in Kashmir Valley would probably slightly exceed 3·9. The number of days when the seeing ranged between 4 and 5 would be very much larger in Kashmir than in Kodaikanal.

The photographs of the sun's disc obtained with the 3-inch photoheliograph at Pampur at different hours of the day are all good and show the sun's limb sharply defined, whilst most of the Kodaikanal plates

show the limb poorly defined. Only one of this series appears equal to a Kashmir plate. The average definition for March and April in Kodaikanal is therefore not nearly equal to the average for May in Kashmir, although March and April are favourable months in Kodaikanal, and the best hour for photographing was chosen.

The series of photographs of sunspots obtained during June with the 4½-inch telescope at Pampur, was compared with the series obtained on the same dates at Kodaikanal with the 6-inch photo-visual telescope. Although the Kodaikanal plates are mostly of good quality not often excelled even during the most favourable months of the year, they do not bear comparison with the Kashmir plates taken with improvised apparatus under considerable difficulties and a smaller optical power. The Kodaikanal plates of course were taken during the most favourable hour of the day, whilst the Kashmir plates were taken at any time the sun happened to be visible; and those taken in the morning, near midday, or in the evening, are all equally good.

The photographic work therefore entirely confirms the visual and indicates the enormous possibilities of progress in the study of solar physics which an observing station established in Kashmir Valley would present.

The spectroscopic observations in Kashmir, as was anticipated, were entirely satisfactory. In sunspot spectra the clear definition of umbra and penumbra, showing radial motion effects, and in the prominences the marvellous detail visible, impressed one with the splendid possibilities for photographic work.

As regards the cloudiness at the two stations, the sunshine records show that the mean annual number of hours of bright sun is practically the same at Kodaikanal and at Srinagar, viz., about 2028 hours. The distribution throughout the year is however different, for at Kodaikanal the winter months are the clearest, and in Srinagar those months are the cloudiest. But in estimating the relative suitability for solar work account must be taken of the fact established by the observations at both stations that at Kodaikanal not more than one hour in six of bright sunshine is available for photography or for detailed spectroscopic study, whilst in Kashmir at least 5 hours out of 6 would be available—a very conservative estimate would give four times the opportunity for work in Kashmir as compared with Kodaikanal, and in addition the quality of the material which could be secured at all times in Kashmir would be equal to the very best that Kodaikanal can produce on occasions when the definition is really good. One of the greatest difficulties experienced in Kodaikanal is the constant interruption of critical photographic work, due either to clouds which tend to cover the sky after 10 A.M., or if clear to bad definition. This involves wastage of photographic plates, as a considerable proportion of those taken have to be rejected from faults entirely outside the control of the observer. In recent years the work at the Observatory has become much more exacting in its requirements, and in order to obtain spectrographic records for measurement and study a complicated series of operations has to be performed, and the large expenditure of time involved is often wasted when, as so frequently happens, the operations are interrupted in the middle by adverse atmospheric conditions.

General Conclusions.

The comparison of Kodaikanal with Kashmir brings out forcibly the disadvantages of a mountain station, especially as regards definition. Hitherto it has been considered by astronomers that the poor midday definition was inevitable and unavoidable, but careful observations made by me both in Kashmir and New Zealand has proved that this is by no means the case; and if one may judge by published spectroheliograms even the low-level observatories of Meudon and Yerkes are able to secure far better midday photographs than Mount Wilson or Kodaikanal. With regard to Mount Wilson and Meudon M. Deslandres remarks :—

"L'Observatoire du Mont Wilson, situé sur une crête élevée, doit souffrir des grands courants de convection que la chaleur solaire développe dans les vallées voisines ; et, en fait, les images solaires n'y sont bonnes que le matin et le soir. A l'Observatoire Lick, où les conditions locales sont les mêmes, les images solaires sont considérées comme mauvaises. Pendant la nuit, d'autre part, au Mont Wilson comme à Lick les images stellaires sont magnifiques et remarquablement calmes.

"L'Observatoire de Meudon, situé sur un petit plateau, a des images bonnes surtout le soir, et aussi parfois pendant la journée, le ciel étant clair ou plutôt légèrement brumeux."*

At Kodaikanal there is a very obvious daily convection current, rising from the southern and eastern slopes of the mountains and evidently due to the strong heating of these slopes and precipices by the morning sun. Although the Observatory is situated some two or three miles from the declivity it does not escape from the bad effects of this current of hot air; for not only is definition ruined soon after 8 A.M., but also masses of cloud are continually forming and dissolving and re-forming in the immediate vicinity of the sun, which renders photographic work extremely difficult after 10 A.M., even if possible at all. This condensation occurs at all times of the year, even in the dry season.

Perhaps the chief advantage of a high-level observatory is the freedom from dust haze, and certainly the air of Kodaikanal is remarkably clear; but as regards practical solar work the advantage of this is somewhat illusory, and at Kodaikanal it is nullified by the prevalence at all times of the year of high thin cirrus clouds, which have a strong tendency to form immediately over the mountain mass, leaving the sky over the plains quite clear. The diffusive and white sky due to this condensation at a great height is of course inimical to most spectographic work, although it is not necessarily injurious to definition.

Long experience of solar research work has convinced me that the main factor which should be considered in selecting a site for a solar observatory is the character of the seeing. All other considerations are of minor importance. Mountain tops have certainly proved a great disappointment, and the reason for this is now clear; it is equally clear that far better conditions exist in some localities. Probably an observatory near sea-level and on the sea-coast would experience better average seeing than one situated on a mountain. There is a uniformity of temperature conditions over the sea, and an absence of convection currents, which is extremely favourable to good definition. Sir John Herschel observing the sun at the Cape of Good Hope, says:—

"What is not a little remarkable, in the hottest *days*, looking *northwards* over the burning tract intervening between Feldhausen and Table, or Saldanha Bay, the most admirable and tranquil definition of the solar spots, and other phenomena of the sun's disc, is by no means unfrequent. In such cases, I presume the strongly heated stratum of air incumbent on the surface of the soil, is swept off by the south-east wind blowing from False to Table Bay, before it ascends high enough to interfere with the visual ray."†

My experience in New Zealand and at Perth in Western Australia shows that in calm weather with a sea-breeze blowing, almost perfect definition may be observed at midday near the sea, however hot the air may be, and it was for this reason I selected a site for the Cawthron observatory on the low hills near the coast at Nelson. Many more imposing sites on the mountains inland were tried, but the definition at high elevations, although better than at Kodaikanal, was found to be far less good than near sea-level; and there can be no doubt from the general purity and blueness of the skies at Nelson that work of the very highest excellence could be carried out at the site chosen.

In India a solar observatory near sea-level would not be practicable, on account of the great heat, which would make the work extremely difficult and trying, except perhaps in the so-called "cold weather" season; but in Kashmir there is the very unique advantage of a temperate climate and considerable elevation above sea-level combined with the extraordinary atmospheric tranquillity in the enclosed valley.

* Annales de L'Observatoire d'Astronomie Physique de Paris. Tome IV, p. 43.

† Cape Observations, Introduction, par. XIX.

KODAIKANAL,
22nd September 1914.

J. EVERSHED,
Director, Kodaikanal and Madras Observatories.

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Kodaikanal Observatory.

BULLETIN No. XLIII.

THE DIFFERENT CHARACTER OF SPECTRUM LINES BELONGING TO THE SAME SERIES.

BY T. ROYDS, D.Sc.

It has been generally assumed that the spectrum lines belonging to the same series are similar in character, and in behaviour under varying experimental conditions. Indeed the similarity in sharpness or diffuseness, or in the direction of unsymmetrical widening, has been a valuable aid in the detection of series relationships in spectra. If, for example, the strong lines of a series were unsymmetrically widened towards the red, the continuation of the series would be looked for in lines widened in the same direction, the widening becoming greater as the higher members were reached. It is therefore of considerable importance to note that there is at least one well-authenticated series in which the character of the lines changes in the course of the series. This is the first subordinate "triplet" series of barium, whose lines are given in Table I, column 5. In this series the first members (λλ 5819, 5800, 5777, 5536, 5519, 5424) consisting of a triplet and satellites, are all unsymmetrically widened towards the red; the second members (λλ 4493, 4489, 4333, 4323, 4264) and probably all succeeding are, on the contrary, unsymmetrically widened towards the violet. This is so surprising and important that it is necessary before proceeding further to make quite sure of our facts. Firstly, there can be little doubt that the first members do really belong to the same series as the higher members; they fit into a formula of the usual type, and have the full complement of satellites analogous to the higher members and to the first subordinate series of calcium and strontium. Secondly, the character of the lines seems equally certain. Although previous investigators of the barium spectrum have not noted the character of the first members of the first subordinate series, the reversals of these lines are in my photographs very eccentrically placed on the violet side of the emission line, indicating unsymmetrical widening towards the red. The character of the second members is obvious, and is given by Kayser and Runge as unsymmetrical towards the violet.[1] There is also the evidence of the displacements at the negative pole compared with the centre of the arc. I have previously shown that lines are displaced at the negative pole in the direction of their greater widening.[2] Investigating the displacement of the barium lines, I find that all the first members of the first subordinate series are displaced to the red (λ 5536·07 is interfered with by an adjacent line), and all the second members to the violet; this is complete confirmation of their opposite character.

It is interesting to examine also the analogous first subordinate series of calcium and strontium. Of the calcium series the first members are in the infra-red and their character is not known; the second members are quite symmetrical so far as can be judged from the symmetry of their reversals and from the smallness of their displacements at the negative pole of the arc,[2] but the higher members are unsymmetrical towards the violet* according to Kayser and Runge[1] and Eder and Valenta[1]. The calcium series is therefore not so extreme a case as that of barium but is still a noteworthy exception to the general run of series. The strontium series is, on the other hand, quite normal if we exclude the infra-red lines whose character is not known. I find that the second members have their reversals slightly eccentrically placed to the red side of their emission lines and that they are displaced to the violet at the negative pole of the arc. These facts indicate that they are unsymmetrical towards the violet and therefore uniform with the higher members whose character has already been observed.[3]

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[1] Kayser, Handbuch der Spectroscopie, Vol. V. [2] Royds, Kodaikanal Observatory Bulletin, No. XL.

* Saunders (Astrophysical Journal, XXXII, 153, 1910) gives the third members as unsymmetrical towards the *red*. This is probably a mistake. The photograph o. Crew and McCauley of the arc in air (Astrophysical Journal, XXXIX, 29, 1914) shows them to be unsymmetrical towards the violet in agreement with Eder and Valenta's observation of the spark lines, and mine of the arc lines.

[3] Kayser, Handbuch der Spectroscopie, Vol. VI.

In brief, the higher members of the first subordinate "triplet" series of calcium, strontium and barium are unsymmetrical towards the violet; the first members of the barium series are unsymmetrical towards the red, the second members of the calcium series are symmetrical, whilst the second members of the strontium series are already unsymmetrical towards the violet.

For convenience of reference I have collected into Table I the lines of the first subordinate "triplet" series of calcium, barium and strontium.

TABLE I.—THE FIRST SUBORDINATE "TRIPLET" SERIES OF CALCIUM, STRONTIUM AND BARIUM.

Order in series.	Calcium.		Strontium.	Barium.
	λ	λ (arc in air) — λ (arc in vacuo).*	λ	λ
First members.	19916·0	...	......	5819·21 (*ur*)
	19864·6	...	30110·7	5800·48 (*ur*)
	19777·4	...	29225·9	5777·84 (*ur*)
	19507·1	...	27856·2	5536·07 (*ur*)
	19452·9	...	26915·4	5519·87 (*ur*)
	19310·6	...	26024·5	5424·82 (*ur*)
Second members.	4456·81 (s)	+ ·011	4971·85 (*uv*)	
	4456·08 (s)	+ ·018	4968·11 (*uv*)	4493·82 (uv)
	4454·97 (s)	+ ·016	4962·45 (*uv*)	4489·50 (uv)
	4435·86 (s)	+ ·009	4876·28 (*uv*)	4333·04 (*uv*)
	4435·13 (s)	+ ·016	4872·66 (*uv*)	4323·15 (uv)
	4425·61	+ ·021	4832·23 (*uv*)	4264·45 (*uv*)
Third members.	3645·14 †	...	4033·25	...
	3644·86 (*uv*) ‡	− ·003	4032·51 (uv)	4087·53 (u)
	3644·50 (*uv*) ‡	+ ·003	4030·45 (uv)	4084·94 (u)
	3631·10 (*uv*)	− ·015	3970·15	3947·6 (u)
	3630·88 (uv) ‡	− ·010	3969·42 (u)	3945·6 (u)
	3624·15 (uv) ‡	− ·001	3940·91 (uv)	...
Fourth members.	3362·42 †	...	......	...
	3362·27 †	...	.. ...	...
	3361·92 (uv)	− ·014	3705·88 (u)	3895·2 (u)
	3350·50 †	...	3653·90 (u)	...
	3350·22 (uv)	− ·010	3653·32 (u)	3767·5 (u)
	3344·49 (uv)	− ·017	3629·15 (u)	..
Fifth members.	...	...	......	...
	3226·26 †	...	......	...
	3225·74 (uv)	− ·021	3547·92 (u)	3787 (u)
	3215·46 †	...	......	...
	3215·15 (uv)	− ·019	3499·40 (u)	...
	3209·68 (uv)	− ·088	3477·83 (u)	...
Sixth members.	...	...	......	...
	3151·41 †	...	......	...
	3150·85 (u)	− ·030	3457·70 (u)	...
	3141·29 †	...	......	...
	3140·91 (u)	− ·062	3411·62 (u)	...
	3136·09 (u)	− ·135	3390·09 (u)	...
Seventh members.	3101·87 (u)	...	3400·39 (u)	...

Note.—(s) denotes symmetrical, (ur) unsymmetrically widened towards the red, (uv) unsymmetrically widened towards the violet, and (u) hazy or diffuse. Those given in italics are new observations; those in roman type are as recorded by other observers.

The chief purpose of the present Bulletin is to point out the importance of determining the pressure shifts of the first subordinate series of calcium and barium, in which, as we have seen, the character of the

* Taken from Crew and McCauley's paper.

† Wavelengths of the arc in vacuo by Crew and McCauley reduced to Rowland's scale.

‡ These lines are given by Saunders as unsymmetrical towards the red, probably by mistake. See footnote on page 109.

lines changes. St. John and Miss Ware as well as Fabry and Buisson have shown that the iron lines which widen unsymmetrically towards the violet undergo large displacements to the violet with increased pressure,[1] and Gale and Adams have confirmed this,[2] whilst those which widen unsymmetrically towards the red undergo large displacements to the red. The interest in these first subordinate series lies in the question whether their lines unsymmetrical towards the violet are, like those of iron, displaced by pressure to the violet, *i.e.*, in the contrary direction to the other lines although belonging to the same series. At present the only evidence available on the point is the difference in the wavelengths of the calcium arc in air (Holtz[3]) and in vacuo (Crew and McCauley[4]). These differences which are given in Table I, whilst they should be accepted with some reserve, show that the lines unsymmetrical towards the violet are displaced to the violet by pressure, and the symmetrical lines of the same series, as was found previously by Humphreys, to the red. It has not been doubted until recently[5] that, as discovered by Humphreys, the pressure displacement $(\delta\lambda/\lambda)$ was constant for all lines belonging to the same series, and this fact has been recommended for the detection of series.[6] Judging from the analogy of the iron lines and from the above results for calcium, however, it appears probable that so far from being constant, the pressure shift may even be in opposite directions for different lines of the same series.

This brings up the whole question of the relationship between pressure shift and series. Humphreys found[7] that the pressure shift, $(\delta\lambda/\lambda)$, was constant for all the lines of the same series, and that the shifts for the principal, the first and second subordinate series were in the ratios 1 : 2 : 4. Although these ratios seem to hold for the majority of cases, about one-third of the total number are exceptions. These exceptions are given in Table II; the mean shifts reduced to λ 4000 at the same pressure for the different series of the same element are quoted from Humphreys' tables. Where data at the same pressure are not available the shift has been calculated from that at a neighbouring pressure and is given in brackets :—

TABLE II.—EXCEPTIONS TO HUMPHREYS' SERIES LAW.

	Series.	Mean shift.	Ratio.
Al	First subordinate	50	1 : 0·8
	Second subordinate	(40)	
Li	Principal	66	1 : 1·5
	First subordinate	(96)	
Mg	First subordinate	35	1 : 1·3
	Second subordinate	45	
Hg	First subordinate	70	1 : 0·9
	Second subordinate	66	
Na	Principal	73	1 : 4·3
	First subordinate *	312	

The shifts were reduced to λ 4000 by Humphreys on the assumption that the absolute pressure shifts are proportional to the wavelength. If the shifts are proportional to some other power of the wavelength than the first some of these exceptions might be brought into line, but on the other hand new ones would be introduced.

Recently Swaim has arrived at entirely different series relationships in studying the pressure shifts of the zinc lines.[5] He finds that the shifts of the lines in the first subordinate series are *inversely* proportional to the cube of the wavelength, in the second subordinate series *inversely* to the first power of the wavelength, and of non-series lines *directly* to the square of the wavelength. There is therefore no direct relation between the first and second subordinate series.

It seems to me exceedingly probable that all these inconsistencies are due to the existence of a density effect superposed on the true pressure effect. When the arc is placed under pressure there is probably not

[1] St. John and Miss Ware, Astrophysical Journal, XXXVI, 14, 1912; Fabry and Buisson, Astrophysical Journal, XXXI, 111, 1910.
[2] Gale and Adams, Astrophysical Journal, XXXVII, 391, 1913.
[3] Holtz, Zeitschrift für wiss. Photographie, 12, 101, 1913.
[4] Crew and McCauley, Astrophysical Journal, XXXIX, 29, 1914.
[5] Swaim, Astrophysical Journal, XL, 137, 1914.
[6] Kayser, Handbuch der Spectroscopie, Vol. II, pp. 327, 579.
[7] Humphreys, Astrophysical Journal, VI, 169, 1897.
* By an unfortunate error or misprint, Humphreys has classed the lines λλ 5682, 5688 as belonging to the second subordinate series of sodium instead of to the first, making it appear as though they conformed to his law.

only an increase in the pressure of the atmosphere surrounding the arc but also an increase in the density of the vapour in the arc owing to a more rapid production of vapour or other cause. The effect of an increase of density is to displace the unsymmetrical lines in the direction of their greater widening, and by an amount apparently dependent only on the degree of unsymmetrical widening.[1] This might explain Swaim's curious results mentioned above. He noted that the amount of displacement under pressure depended on the diffuseness of the line, and since the series lines he measured are unsymmetrical towards the red it seems probable that the large displacements to the red he obtained for the higher and more unsymmetrical members of the series are due, at any rate in part, to increased vapour density.

Many of the anomalous results obtained by Duffield in the arc under pressure are also probably due to density effects. Duffield found that when unsymmetrical lines are reversed the displacement of the reversal falls to half of that of the unreversed line, whilst the reversals of symmetrical lines remain normally displaced.[2] Now the unsymmetrical lines are those sensitive to density shift and it would be expected that at the lower density of the absorption line their displacement would be smaller, whilst symmetrical lines would be unaffected. He also finds that the displacement of a line may have two alternative values at one and the same pressure.[3] Duffield says,[4] "Whatever the nature of the disturbing cause, Group III and then Group II [of the iron lines] are most susceptible to it." The lines of Group III, all unsymmetrically widened towards the red, are those most susceptible to density shift,[5] whilst the lines of Group II, much widened but not unsymmetrically by pressure, have not been sufficiently investigated. He further says,[6] "On the photographs showing abnormal displacements [approximately twice the normal values], the reversals are more numerous and broader than they are on plates giving normal values"; this observation is direct evidence of increased density. I admit, however, that there is no obvious reason why the ratio of the larger displacement to the smaller should be approximately as 2 : 1.

An additional interest for the investigation of the calcium lines under pressure is the question of the behaviour of Fowler's series of narrow triplets (λλ 4586, 4581, 4878; etc). According to Moore, the Zeeman effect for these lines is either zero or at least very small,[7] and therefore their pressure displacement would be expected to be small also.[8] It will, however, not be conclusive if they prove to have large displacements in the *arc* under pressure, since these lines are easily displaced by density.[1]

For the elucidation of the relationship between pressure shift and series, as well as for the solution of solar problems it seems essential to isolate the pressure effect from the density effect. The means of doing this are not obvious and the only hope seems to lie in investigating the furnace spectrum under pressure rather than the arc spectrum, for in the furnace the vapour density, dependent on the rate of production and of disappearance of vapour, is almost certainly influenced by pressure to a much less degree than in the arc. All that we know at present is that since the density effect is very small for symmetrical lines their shifts in the arc under pressure are probably due to pressure only, but that the shifts of unsymmetrical lines are partly, at least, due to density. Mr. Evershed suggests to me that the shift to the violet found in the arc under pressure for certain iron lines may be entirely a density effect, and an observation of Humphreys[9] supports this view. It certainly seems probable that many of the laws of pressure shifts will be modified, and it is hoped simplified, if experiments can be conducted under conditions of constant vapour density. The elimination of density effects in order to obtain true pressure shifts is one of the most pressing problems for those interested in the displacements in the sun's spectrum.

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[1] Royds, Kodaikanal Observatory Bulletin, No. XL.
[2] Duffield, Phil. Trans. Roy. Soc., A. 208, p. 151, 1908.
[3] Duffield, Phil. Trans. Roy. Soc., A. 209, p. 216, 1909.
[4] Duffield, Phil. Trans. Roy. Soc., A. 209, p. 216, 1909.
[5] Royds, Kodaikanal Observatory Bulletin, Nos. XXXVIII and XL.
[6] Duffield, Phil. Trans. Roy. Soc., A. 208, p. 161, 1908.
[7] Moore, Astrophysical Journal, XXXIII, 385, 1911.
[8] See King, Astrophysical Journal, XXXI, 433, 1910, and Humphreys, Astrophysical Journal, XXIII, 233, 1906; XXVI, 18, 297, 1907; XXVII, 194, 1908.
[9] Humphreys Astrophysical Journal, XXXI, 459, 1910.

THE OBSERVATORY, KODAIKANAL,
29th September 1914.

T. ROYDS,
Assistant Director.

Kodaikanal Observatory.

BULLETIN No. XLIV.

ON THE DISPLACEMENTS AT THE SUN'S LIMB OF LINES SENSITIVE TO PRESSURE AND DENSITY.

BY A. A. NARAYANA AYYAR, B.A.

In a discussion of the displacements of spectrum lines at the sun's limb[1], Messrs. Evershed and Royds have shown that iron lines displaced to the violet by increased pressure are shifted, in common with the majority of lines, to the red of their position at the centre of the disc. The hypothesis that the pressure of the effective level of absorption at the limb is greater than that at the centre of the disc, requires that these lines should be shifted to the violet and not to the red. From the small relative shift of these lines compared with the shift of those displaced to the red by pressure, they concluded that the difference of pressure of the effective levels of absorption at the sun's limb and at the centre of the disc was small.

It should be remembered that, in the reversing layer, the vapour density of any element will vary proportionately with the total pressure if the relative amounts of the various elements remain constant, and therefore any increase or decrease of pressure at the limb compared with the centre of the disc will be accompanied by a corresponding increase or decrease of vapour density.

Now, certain lines, particularly of calcium and sodium, are much more sensitive to pressure and density than iron lines. The limb shifts of these lines, therefore, provide a more rigorous test than the iron lines as to whether there is a large difference of pressure and density between the sun's limb and the centre of the disc. The lines available as being sensitive to pressure or to density are as follows :—(1) the sodium pairs at $\lambda\lambda$ 5680 and 6150, (2) the calcium triplets at $\lambda\lambda$ 3950, 4580 and 6120 and (3) the magnesium lines at $\lambda\lambda$ 4352 and 4703. All these lines are unsymmetrically widened towards the red and undergo, with increased pressure or density, large displacements to the red. It will be shown in the following paragraphs that a comparison of the limb shifts of these lines with those of other lines of the same level shows that the difference of pressure and density between the effective levels at the limb and at the centre of the disc must be very small.

Experimental Details.[2]

The spectrograph has been already described in Kodaikanal Observatory Bulletin No. XXXVI. The method of making exposures of the centre and both the limbs simultaneously is the same as that given in Kodaikanal Observatory Bulletin No. XXXIX. In the region λ 6150 some of the plates were also obtained by alternate exposure of the centre and each limb separately. Observations were made between latitudes 0° and 75° at a distance of one-thirtieth of the sun's radius inside the limb. The higher latitudes were in the regions $\lambda\lambda$ 5680 and 6150. In the region λ 6150 the second order spectrum was used ; in the other regions the third order was employed.

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[1] Kodaikanal Observatory Bulletin No. XXXIX.

[2] The photographs were taken by the Director and Assistant Director.

The following table contains the limb — centre shifts of all the lines measured :—

TABLE I.—LIMB — CENTRE SHIFTS.

[Lines most sensitive to pressure and density are marked ur, being unsymmetrically widened towards the red.]

λ (Rowland).	Intensity.	Number of measures.	Limb — centre.		λ (Rowland).	Intensity.	Number of measures.	Limb — centre.	
			Kodaikanal.	Mt. Wilson.				Kodaikanal.	Mt. Wilson.
			A/1000	A/1000				A/1000	A/1000
3949·039 (*ur*)	Ca 1	3	+ 7	...	4733·779	Fe 4	2	+ 7	+ 10
3950·102	Fe 5	4	+ 6*	+ 6	5655·715	Fe 2	2	+ 10	...
3956·819	Fe 6	5	+ 6*	+ 7	5659·052	Fe 4	5	+ 9	...
3966·212	Fe 8	8	+ 4*	...	5662·744	Fe 4	5	+ 8	...
3969·418	Fe 10	5	+ 4*	...	5667·739	Fe 2	1	+ 8	...
3977·891	Fe 6	6	+ 7*	+ 6	5679·249	Fe 3	4	+ 8	...
4076·792	Fe 4	2	+ 4	...	5682·889 (*ur*)	Na 5	5	+ 4	+ 7
4078·515	Fe 4	2	+ 5	...	5684·710	Si 3	5	+ 7	+ 10
4081·038	Fe 2	2	+ 4	...	5688·436 (*ur*)	Na 6	5	+ 3	+ 6
4085·161	Fe 4	2	+ 5	...	5690·646	Si 3	4	+ 8	+ 8
4089·874	Fe 3	2	+ 4	...	5691·715	Fe 2	1	+ 9	...
4091·711	Fe 3	2	+ 6	...	5701·323	Si 1	1	+ 6	+ 7
4095·094 (*ur*)	Ca 4	4	0	+ 4	5701·772	Fe 4	4	+ 7	...
4096·129	Fe 3	2	+ 4	...	5706·215	Fe 3	1	+ 6	...
4098·689 (*ur*)	Ca 4	4	+ 2	...	5708·622	Si 3	4	+ 9	+ 9
4387·216	Fe 5	2	+ 7	+ 8	5709·601	Fe 5	4	+ 7	...
4352·088 (*ur*)	Mg 5	4	+ 4	+ 4	5709·775	Ni 5	4	+ 12	+ 12
4352·908	Fe 4	1	+ 6	+ 6	6065·709	Fe 7	4	+ 4	+ 12
4527·101 (*ur*)	Ca 3	7	+ 4	+ 7	6079·227	p Fe 2	8	+ 4	+ 12
4528·798	Fe 8	4	+ 6	+ 5	6102·392	Fe 6	7	+ 3	+ 18
4531·327	Fe 5	4	+ 8	+ 7	6102·937 (*ur*)	Ca 9	7	+ 3	+ 8
4548·024	Fe 3	4	+ 6	+ 8	6122·434 (*ur*)	Ca 10	8	+ 3	+ 7
4549·642	p Fe 2	4	+ 6	+ 8	6136·829	Fe 8	8	+ 5	+ 18
4556·068	p Fe 8	4	+ 8	+ 11	6151·834	Fe 4	8	+ 3	+ 12
4560·266	Fe 2	3	+ 7	...	6154·438 (*ur*)	Na 2	6	+ 3	+ 11
4578·782 (*ur*)	Ca 3	5	+ 3	...	6160·956 (*ur*)	Na 3	8	+ 2	+ 12
4581·575 (*ur*)	Ca 4	6	+ 3	...	6162·390 (*ur*)	Ca 15	8	+ 2	+ 8
4584·018	p Fe 4	4	+ 8	+ 12	6166·651	Ca 5	8	+ 4	+ 9
4586·047 (*ur*)	Ca 4	6	+ 2	+ 6	6169·249	Ca 6	8	+ 3	+ 10
4592·840	Fe 4	2	+ 8	...	6169·778	Ca 7	8	+ 4	+ 9
4595·540	Fe 2	2	+ 8	...	6173·558	Fe 5	8	+ 5	+ 14
4598·303	Fe 3	2	+ 6	...	6175·584	Ni 3	8	+ 3	+ 11
4603·126	Fe 6	2	+ 6	...	6191·393	Ni 6	8	+ 2	+ 11
4607·831	Fe 4	2	+ 8	...	6191·779	Fe 9	8	+ 5	+ 14
4679·027	Fe 6	1	+ 4	...	6213·644	Fe 6	8	+ 4	+ 14
4703·177 (*ur*)	Mg 10	3	+ 4	+ 8	6219·494	Fe 6	4	+ 6	...
4707·457	Fe 5	3	+ 5	...					

* These values are taken from Kodaikanal Observatory Bulletin No. XXXIX.

For comparison, Dr. Adams's values are also given under the heading "Mount Wilson." Generally there is a fair agreement except in the region λ 6150, where my values are much smaller than Adams's. The cause of this is not clear. As stated above, the plates in this region have been obtained both by comparison of each limb separately with the centre of the disc and also by simultaneous exposure of both limbs and the centre in a manner identical with that of photographs in other regions giving good agreement with Adams. My experience agrees with that of other workers, who have found that the value for the limb shifts vary considerably from plate to plate in an apparently arbitrary manner; in a particular plate, while the majority of lines may have their average values some may have abnormal values, notwithstanding the fact that they give correct values for the rotational velocity of the sun. Whether these variations are due in some way to the photographic process, such as the unequal shrinking of the film in drying, or are real phenomena having their origin in the sun is a matter for investigation.

Comparison of the shifts of sensitive lines with those of other lines.

In Kodaikanal Observatory Bulletin Nos. XXXVIII and XL, Dr. Royds has shown that an increase of density displaces unsymmetrical spectrum lines in the direction of their greater widening. So far as we know, the pressure displacements are also in this direction. Consequently, the limb—centre shifts of lines unsymmetrically widened towards the red will be greater or less than those of symmetrical lines at the same

level according as the pressure and density at the limb are greater or less than at the centre of the disc. The lines chosen for comparison with these sensitive lines should be symmetrical lines originating at the same level as the sensitive lines in order to eliminate differences of velocity depending on level in the reversing layer.[1] According to St. John's values for the radial motion in sunspots, the level of the sensitive lines λλ 3949 (Ca), 4095 (Ca), 5682 (Na), and 5688 (Na) is the same as that of the iron lines of intensity 2 to 4, and the level of the magnesium lines λλ 4352 and 4703 is the same as that of the iron lines of intensity 6 to 7. The average limb—centre shifts of these lines are compared in the following table :—

TABLE II.—AVERAGE LIMB DISPLACEMENTS OF SENSITIVE LINES COMPARED WITH THOSE OF IRON LINES AT THE SAME LEVEL.

Sensitive lines.	Mean shift.	Iron lines at the same level.	
		Mean shift.	Intensity.
3949, 4095, 5682 and 5688	+ 0·0035 A ...	+ 0·0070 A*	2 to 4
4352 and 4703	+ 0·0040 A ...	+ 0·0047 A*	6 to 7

* These values are from Kodaikanal Observatory Bulletin No. XXXIX, Table II.

It will be apparent from the above table that the limb shifts of lines sensitive to pressure and density are smaller than those of iron lines at the same level.

The shifts of all the sensitive lines measured, compared with those of iron lines on the same plates, are given in Table III.

TABLE III.—AVERAGE DISPLACEMENTS (LIMB — CENTRE) OF SENSITIVE LINES, COMPARED WITH THOSE OF IRON LINES ON THE SAME PLATES.

Sensitive lines.	Mean shift.	Neighbouring iron lines.		
		Mean shift.	Number of lines.	Mean Intensity.
3949·039 Ca	+ 0·0070 A ...	+ 0·0054 A	5	6·0
4095·094, 4098·689 Ca	+ 0·0010 ...	+ 0·0046	7	3·3
4352·083, 4703·177 Mg	+ 0·0040 ...	+ 0·0058	5	4·8
4527·101, 4578·732, 4581·575, 4586·047 Ca	+ 0·0030 ...	+ 0·0070	9	4·1
5682·869, 5688·436 Na	+ 0·0035 ...	+ 0·0080	9	3·2
6102·937, 6122·434, 6162·390 Ca ... ... } 6154·438, 6160·956 Na ... ... }	+ 0·0026 ...	+ 0·0044	8	6·4

Here again it is seen that the shifts of sensitive lines are generally smaller than those of iron lines which are less sensitive. The line λ 3949 is the only apparent exception, which may probably be accounted for by the higher level of the iron lines with which it is compared, as judged by their mean intensities.

[1] See odaikanal Observatory Bulletin No. XXXVI, page 52.

We are led to the same conclusion if we compare the unsymmetrical calcium lines with the symmetrical calcium lines.

These results seem to point to slightly lower pressure and density at the limb than at the centre of the disc, since lines displaced most to the red by pressure and density have a slight *relative* shift to the violet.

Absolute limb—centre shifts of sensitive lines.

According to Humphreys, the mean pressure shift for the sodium lines λλ 5682 and 5688 is +·055 A per atmosphere and that for the calcium lines λλ 6102, 6122, and 6162 is +·024 A per atmosphere. The mean limb—centre shifts for these two groups of lines are +·004 A and +·008 A respectively. Even assuming that the absolute limb—centre shift is entirely due to pressure, it is interesting to find that the difference of pressure between the limb and the centre can only be a fraction of an atmosphere.

Conclusion.

We see, therefore, that, even taking the limb shifts of lines much more sensitive to pressure and density than the iron lines, the difference of pressure and density between the limb and centre is very small, in agreement with the conclusions of Messrs. Evershed and Royds for iron lines. The balance of evidence is in favour of slightly lower pressure and density at the limb than at the centre of the disc.

I take this opportunity to express my thanks to Dr. Royds, at whose instance the work was taken in hand and whose many suggestions at various stages have been of invaluable help to me.

The Observatory, Kodaikanal,
29*th October* 1914.

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Third Assistant.

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Kodaikanal Observatory.

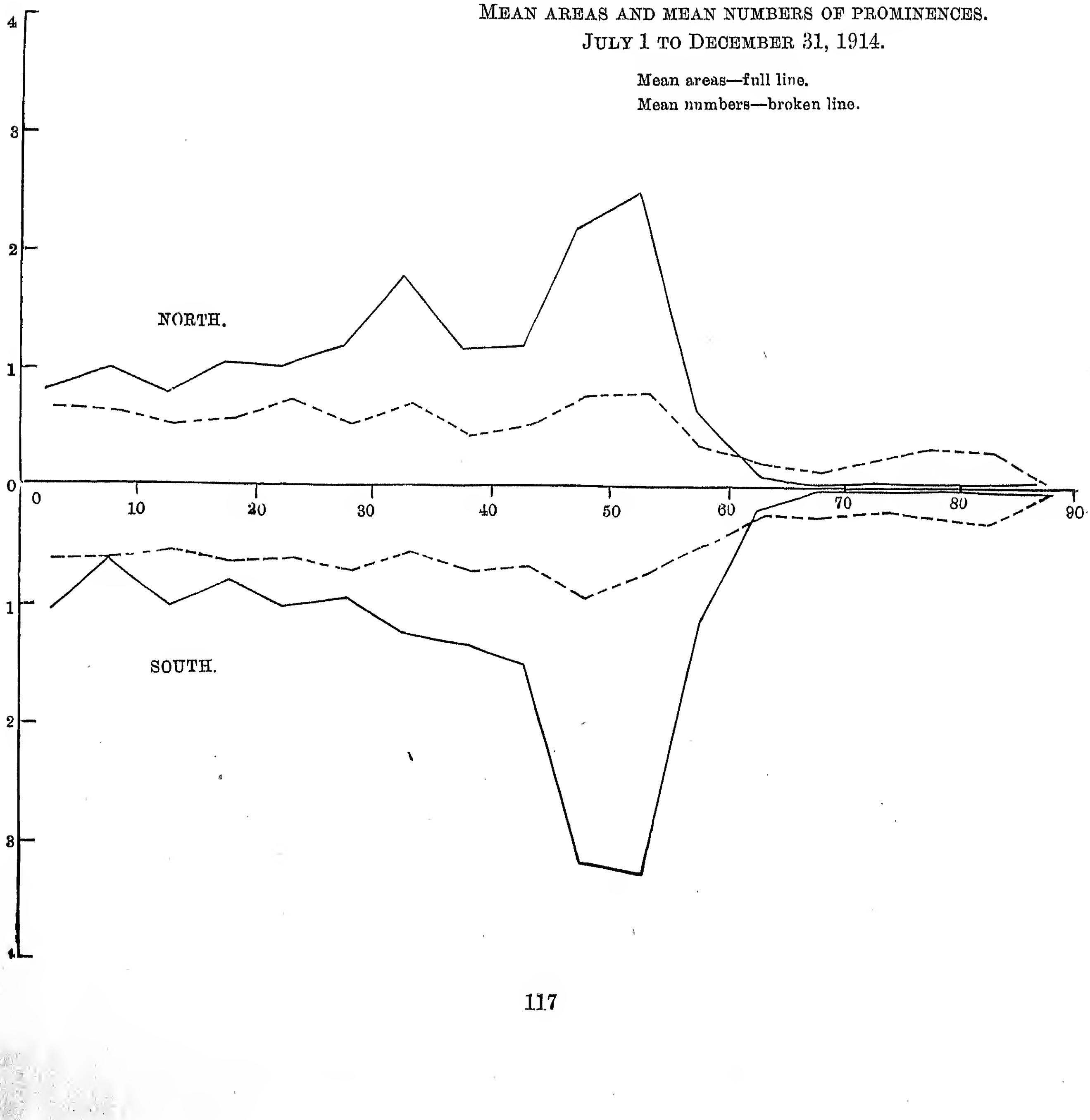
BULLETIN No. XLV.

SUMMARY OF PROMINENCE OBSERVATIONS FOR THE SECOND HALF OF THE YEAR 1914.

From October 1, 1914, visual observations of prominences were practically confined to displacements of the hydrogen lines, and metallic prominences, as the position angles, heights and areas can now be much more satisfactorily determined from the photographs.

The distribution in latitude of the prominences observed and photographed during the six months ending December 31, 1914, is represented in the accompanying diagram. The full line gives the mean daily areas, and the broken line the mean daily numbers for each zone of 5° of latitude. The ordinates represent tenths of square minutes of arc for the full line and numbers for the broken line. The means are corrected for partial or imperfect observations, the total of 140 days being reduced to 113 effective days.

MEAN AREAS AND MEAN NUMBERS OF PROMINENCES.
JULY 1 TO DECEMBER 31, 1914.



The mean daily areas and daily numbers for each hemisphere corrected for partial observations are as follows :—

	Mean daily areas (square minutes).	Mean daily numbers.
North	1·59	8·97
South	1·75	9·10
Total	3·34	18·07

Compared with the first six months of the year the mean areas have increased while the mean numbers have diminished, showing that larger prominences occurred during the latter half of the year. The distribution in latitude is much the same as during the earlier months but the zones of greatest activity have advanced in latitude about 5° and are symmetrically placed at 50° north and south. The zones between latitude 45° and 55° are, roughly speaking, about twice as active as the regions nearer the equator which show little variation even down to the equator itself.

The monthly, quarterly, and half-yearly frequencies and the mean height and extent are given in the following table. The frequencies are derived from the effective days.

Abstract for the second half of 1914.

Month.	Number of days of observations.		Number of prominences.	Mean daily frequency.	Mean height.	Mean. extent.
	Total.	Effective.				
1914.					″	°
July	16	11	147	13·4	34·4	1·61
August	27	20	431	21·6	30·7	1·50
September	29	22	413	18·8	28·2	1·83
October	19	16	211	13·2	36·1	2·09
November	27	24	459	19·1	31·8	2·28
December	22	20	394	19·7	30·5	2·42
Third quarter ...	72	53	991	18·7	30·2	1·45
Fourth quarter	68	60	1,064	17·7	31·9	2·27
Second half-year ...	140	113	2,055	18·2	31·1	1·87

The quarterly results, including those given in Bulletin No. XLI, show that a steady increase has occurred in the mean height and extent of the prominences during the whole year, while the mean frequencies diminished from 23·6 in the first three months of the year to 17·7 during the last three months. The increase in size of the prominences however more than compensates for the reduction in numbers.

Distribution east and west of the sun's axis.

Prominence numbers show a slight and areas a considerable eastern preponderance, which in the latter case was maintained in every month of the half year. The distribution was as follows :—

1914 July to December.	East.	West.	Percentage east.
Numbers observed	1,037	1,018	50·46
Total areas in square minutes of arc	2,121	1,644	56·33

Metallic prominences.

The following metallic prominences were recorded in the half year :—

TABLE I.—LIST OF METALLIC PROMINENCES. JULY—DECEMBER, 1914.

Date.		Hour I.S.T.		Base.	Latitude.		Limb.	Height.	Lines reversed.
					North.	South.			
1914.		H.	M.	°	°	°		"	
July	31	8	48	5	20	...	W	30	6078·1, D_1, D_2, 5316·8, b_1, b_2, b_3, b_4, 5018·6, 5016·3, 4924·1. Eruptive.
August	8	9	18	—	...	31	E	20	D_1, D_2, b_1, b_2, b_3, b_4. Changing.
October	11	8	15	12		49·5	E	65	D_1, D_2, b_1, b_2, b_3, b_4, 5316·8, 4924·1.
November	4	11	55	1	21	...	W	30	D_1, D_2, b_1, b_2, b_3, b_4. Associated with a spot.
	25	8	52	10	50	..	W	60	D_1, D_2 slightly bright near base.
December	12	9	0	1	25	...	E	20	D_1, D_2, b_1, b_2, b_3, b_4.
	12	9	0	—	23	...	E	20	D_1, D_2, b_1, b_2, b_3, b_4.
	21	8	50	1	42·5		E	15	D_1, D_2, b_1, b_2, b_3, b_4.
	26	8	28	1	52	...	W	20	D_1, D_2, b_1, b_2, b_3, b_4.
	31	8	42	1	22	...	E	15	D_1, D_2, b_1, b_2, b_3, b_4.
	31	8	44	2	13	...	E	30	D_1, D_2, b_1, b_2, b_3, b_4. Associated with a spot.
	31	9	5	3	18·5	...	W	20	D_1, D_2, 5316·8, 5269·7, 5234·8, b_1, b_2, b_3, b_4, 4924·1. Associated with a spot. Changing; height 20" at $9^h\ 5^m$, 30" at $9^h\ 9^m$ and 40" at 9^h 11m, but only 10" at 9^h 15m. In Ca photo at $8^h\ 18^m$ the height was 50".

Displacements of the hydrogen lines.

Particulars of these disturbances are given in the following table :—

TABLE II.—DISPLACEMENT OF THE C LINE IN PROMINENCES. JULY—DECEMBER, 1914.

Date.		Time. I.S.T.		Latitude.		Limb.	Amount of displacement.			Remarks.
				N.	S.		Red.	Violet.	Both ways.	
1914.		H.	M.	°	°		A.	A.	A.	
July	31	8	48	20		W		1·5		Metallic prominence.
August	1	9	20	18		W		2		At top of prominence.
	11	10	05		69	W		0·5		
	12	9	53	58·5		E				C bulging to violet over 2°.
	12	9	35	14		E		2		At top of prominence.
	12	9	21		60·5	W	Slight			
	12	10	2	11		W	1			Not seen at 10h 7m.
	12	8	25	56·5		W	1			
	12	8	21	71		W	0·5			Not seen at 9h 58m.
	12	9	57	78		W	1			At top of prominence.
	15	9	15		39·5	W	1			Over whole prominence.
	17	9	30		44	W		Slight		At base of prominence.
	17	9	35		46·5	E			Slight	No prominence.
	20	9	26		82	E	Slight			
	20	9	3		71	W	Slight at base	Slight at top		
	22	8	38	68·5		E	0·5			At top of prominence.
	22	8	18		69	E		1		
	23	8	44		68	W		Slight		At top of prominence.
	26	9	1	79·5		E	3			Very rapid changes in form and amount of displacement—5A at 9h 5m and 9h 8m, ; only about 1A at 9h 9m.
	26	8	28	73·5		W	Slight			No prominence.
	30	8	33	81		E	Do.			
September	1	8	40		34·5	E		Slight		No prominence
	2	9	9		83	W		0·5		At top of prominence.
	4	11	48		80·5	W		Slight.		
	5	8	20		53	E		1		No prominence.
	6	8	47	78		E	1			Do.
	6	8	58		12	E		1		Do.

Date.		Time I.S.T.		Latitude.		Limb.	Amount of displacement.			Remarks.
				N.	S.		Red.	Violet.	Both ways	
1914.		H.	M.	°	°		A	A	A	
September	6	8	32		75·5	E			Slight	
	6	8	28		5	W		1		At top of prominence.
	6	8	13	67·5		W		1		No prominence.
	6	8	9	72		W	0·5			At base of prominence. 45″ high; prominence 20″ high at 8h 44m and the displacement extended over the whole of it. Prominence gone at 9h 20m but C was slightly displaced to red.
	8	12	0		50·5	E		Slight		
	9	9	20		19·5	E	1			
	9	9	16		25	E		0·5		At top of prominence.
	9	9	26		59·5	E	1			No prominence.
	11	8	40		29	E	2	1·5		At two different points.
	20	10	47		19	W			Slight	No prominence.
	24	11	33		30	W	Slight			
	27	8	20	70·5		E	Do.			
	27	8	40		36·5	E	0·5 at top	Slight at base		
	27	9	59	55		W	Slight			At top.
	27	8	18	83		W		Slight		
	28	9	49	31·5		W	Do.			No prominence.
	30	8	48		42·5	W	Do.			At base.
	30	8	34	33		W	0·5			
	30	8	29	39·5		W	0·5			No prominence.
	30	8	28	42·5		W	Slight			Do.
October	1	9	2		3·5	E	2			No prominence. A small prominence visible at 9h 4m. The prominence was 40″ high in Ca at 9h 28m.
	1	9	15		50	E		Do.		
	1	9	17		69	E		Do.		
	1	9	24		36	W		Do.		
	1	9	29	50		W		1		Not seen at 9h 30m.
	2	8	40		65	E	2 at top	1·5 at base		
	3	8	40	75·5		E	Slight at top	0·5 at base		No prominence at 9h 6m, but C was slightly displaced both ways.
	4	10	26	48·5		E		Slight		At top of prominence.
	5	8	26		34	E		1		
	5	8	24		42	E		Slight		
	5	8	49		82	E	2			Displaced portion detatched from C line. Not seen at 9h 5m.
	5	9	13		50	W		Do.		
	5	8	27		23	W	Slight	Do.		At two different points.
	11	8	15		49	E	0·5			
	11	8	57		58·5	E	0·5			No prominence.
	23	8	17	34		E		1		Do.
	23	8	13	27·5		E		Slight		At top of prominence.
	23	8	26		35	E	Slight at base	Slight at top		
	31	9	14		23	W		1		Over whole prominence.
November	1	8	9	18·5		W		0·2		No prominence.
	1	8	9	20		W		0·5		Do.
	1	8	1	74·5		W		0·2		Do.
	3	9	10		18	E		Slight		At base of prominence.
	3	8	46	27		W			Slight	No prominence.
	4	11	48		81·5	E		0·5		Do.
	4	11	55	21		W	1	0·5	1 at 14h 15m.	
	10	8	59	59		W		0·5		Do.
	11	8	31	17·5		E		0·5		Do.
	11	8	38		38	E		Slight		Do.
	13	9	9	43·5	...	E	Slight			Do.
	13	8	42	53		W	Do.			Do.
	13	8	40	67		W		0·5		Do. Chromosphere bright.
	14	8	29		25·5	E		0·5		At base of prominence.
	14	8	27		35	E		Slight		
	14	8	50		79·5	W	1	0·5		No prominence.
	14	8	28		57	W	2			Over whole prominence.

Date.		Time I. S. T.		Latitude.		Limb.	Amount of displacement.			Remarks.
				N.	S.		Red.	Violet.	Both ways.	
1914.		H.	M.	°	°		A.	A.	A.	
November	15	8	40	29		W	1			Gone at 8h 44m.
	16	8	46		87	E	0·3			
	16	8	55	10		W		0·2		Over whole prominence and over an extent of 3°.
	18	8	48	46·5		E		Slight		No prominence.
	18	8	41	20		E		0·5		
	18	8	57		80·5	E		0·5		
	18	8	58		77·5	W		1		Do.
	19	8	53	43		E	0·5			Over whole prominence.
	19	8	41	20·5		E		Slight		
	19	8	35		28·5	E	0·3	Do.		No prominence.
	19	8	28		58	E		Do.		Do.
	19	9	7	59		W	0·2			
	20	8	23	87		E		0·5		2A at 8h 23½m and 0·5 A at 8h 24m.
	24	8	37		78	E	Slight at base	Slight at top		Gone at 9h 5m.
	24	8	58	44		W	Slight			No prominence.
	25	8	56		17·5	W	1·5			
	25	8	45	80		E		1		
	26	8	41		44	E	Slight			
	27	9	52	12		W	0·5			
December	9	8	42	32·5		E		Slight		Do.
	9	8	44	13		E			Slight	Do.
	9	9	2		30	W		Do.		Do.
	9	8	58		4	W		0·5		Do.
	10	9	10	41		E	0·2			
	10	9	14	15		E	Slight			
	10	9	16	3		E		Slight		No prominence. Displacement at two points close to each other.
	10	8	52	21		W		Slight		Over whole prominence in Hα. No prominence in Ca. Displacement gone at 8h 57m.
	11	8	53		56	W		0·5		
	11	8	58		25	W		Slight 1 A at 8h 59m.		
	12	9	0	25		E		0·5		
	12	9	14		20	E		Slight		
	12	8	21		49	W	Slight			At top of prominence.
	13	8	54	23·5		E	Slight			No prominence.
	13	8	48	14·5		E	0·2			
	13	8	45		5	E		1·5		No prominence.
	13	9	4		26	W	Slight			Do.
	15	9	20	28		E		Slight		
	15	9	26		72	E	0·3			
	15	8	43	52		W		Slight		
	16	9	10	88·5		E	0·5			
	16	9	6	23		E			Slight	
	16	9	16		56	W	0·5 at top.			
	16	9	18	18—23		W			Slight	At several points.
	17	8	59		49	E	0·5	Slight		No prominence.
	17	8	43		80·5	E			Slight	Do.
	17	8	33	56		W		2		
	17	9	5	80·5		W		1		Do.
	18	9	40	74		W		2		Do.
	20	8	31		76·5	E		0·5		Do.
	20	8	58		22	W	2	1		Do. Displacement slight at 9h 18m.
	21	8	42		71	W	Slight			
	21	8	25	77		W		Slight at top		Do.
	22	8	42	41		E		0·3		
	22	8	51		50	W	Do.			Do.
	24	8	58		27—29	E		Slight at base		0·5A to violet at—27° E.
	25	8	54	88		E	Do.			No prominence.
	25	8	35	68		E		Slight		Do.
	25	8	35	63		E		Do.		Do.

Date.		Time. I.S.T.		Latitude.		Limb.	Amount of displacement.			Remarks.
				N.	S.		Red.	Violet.	Both ways.	
1914.		H.	M.	°	°		A.	A.	A.	
December	25	8	25	18·5		E		Slight		
	25	8	40		45	W		Do.		
	25	8	46	16		W		0·5		
	25	8	50	40-50		W		Slight		At about a dozen points.
	25	8	54	82·5		W	Slight			No prominence.
	25	8	54	83·5		W		0·5		Do.
	26	8	55	21		E			Slight	Do.
	26	8	60	16		E		2		Do. Not seen at 8^h 55 m.
	26	9	3		49	E	0·2			
	26	9	6		84·5	E		0·5		Do.
	26	8	28	52		W		Slight at base		
	26	8	25	77		W	0·3			Do.
	27	8	39	46		E	Slight			
	27	8	52	82		W		Slight		
	28	8	20	77		E	2			Not seen at 8h 22m when C was displaced to violet for 0·5A.
	28	8	23	60		E		1		Changing rapidly 2A at 8^h 25^m. Nothing at 8h 27m.
	28	8	15		51·5	W	Slight			
	29	8	34	41		E	0·5			
	29	8	25		53	E		1		Over whole prominence.
	29	8	25		50	E		1		At top only.
	30	8	57		51	E		Slight		
	31	9	5	18·5		W		0·2		Displacement 1A at 9h 11m.
	31	9	5	50		W		1		At base.

Eighty-six of these displacements were in the northern hemisphere and seventy-eight in the southern; eighty-seven were in the eastern hemisphere and seventy-seven in the western. There was a decided increase in the displacements to the violet. Ninety-eight were towards the violet and seventy towards the red. A number of prominences showed displacements to the red in one part and to the violet in another part. Displacements both ways at the same point were recorded in ten prominences.

The displacements were recorded fairly uniformly over the whole limb, fifty-one were 0° to 30° of latitude, sixty from 31° to 60° and fifty-three from 61° to 90°.

Reversals and displacements of the C line on the disc.

Eighty-five reversals of the C line were observed in the neighbourhood of spots or occasionally near faculæ only. These as well as the darkenings of the D_3 line show a slight preponderance in the eastern hemisphere while the number of displacements of the C line in or near spots was slightly in excess on the western. The table following gives the distribution east and west of these phenomena :—

	East.	West.
Reversals of C near spots	44	41
Darkening of D_3	6	4
Displacements of C	20	22

There was a preponderance of the displacements towards red, twenty-five being towards red and eleven towards violet. The double spot group which crossed the central meridian on November 9 showed a prominence-like reversal on the 10th, and on the 11th there were displacements indicating violent changes in the direction and amount of the movement.

Prominences projected on the disc as absorption markings.

The grating spectroheliograph for photographing the absorption markings in hydrogen light was not in regular use but a few plates were obtained towards the end of the year. A considerable number of absorption markings are shown on the calcium spectroheliograms and there is no doubt that they have increased in

frequency since 1913 or the first half of 1914. Most of the markings are in the south-eastern quadrant of the sun's disc and correspond to the high latitude zone of prominence activity at about 50° south; from the middle of November however absorption markings appeared in the north-east quadrant in latitudes ranging from + 18° to + 70°. The great preponderance of these markings on the eastern side of the central meridian is very remarkable as it exceeds considerably the eastern preponderance of the prominences at the limb.

THE OBSERVATORY, KODAIKANAL,
24th February 1915.

J. EVERSHED,
Director, Kodaikanal and Madras Observatories.

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Kodaikanal Observatory.

BULLETIN No. XLVI.

THE DISPLACEMENTS OF THE ENHANCED LINES OF IRON AT THE CENTRE OF THE SUN'S DISC.

By J. EVERSHED AND A. A. NARAYANA AYYAR.

The general displacement of the solar lines towards the red has been interpreted in Bulletin No. XXXVI as due to movements of the solar gases in the line of sight, and not to pressure as had been formerly believed. The movement is one of recession from the earth, or a falling movement at the centre of the sun's disc. This would suggest a circulation of the solar gases in a radial direction, the cooler gases falling from the higher parts of the sun's atmosphere, and these being replaced by hotter gases ascending from below. In discussing some eclipse spectra obtained in 1900 it was suggested that a circulation of this kind might account for the relatively great intensity of the enhanced lines of iron and other substances in eclipse spectra, as compared with their intensities in the Fraunhofer spectrum, "The highly heated ascending gases giving the predominant features to the flash spectrum, whilst the cooler more diffused gases slowly subsiding determine the character of the absorption spectrum." *.

With a view to detecting the rising movement of the hotter gases, a special study has been made of the enhanced lines of iron in the sun and in the electric arc. The spectrograph used is the same as was described in Bulletin No. XXXVI, but for most of the work a new grating ruled by Anderson was employed. This has a ruled surface 5 by 4 inches with a total of 75,080 lines. The third order spectrum was used in the green and blue parts of the spectrum, and the second order in the red. As in previous investigations of this nature the electric arc and the centre of the sun's disc were photographed simultaneously, using a reflecting device placed in front of the slit. The enhanced "spark" lines of iron were obtained by using a very short arc between iron electrodes, carrying a current of 10 to 12 ampères. Under these conditions the enhanced lines are readily photographed, and they appear all to be of the same character, narrow symmetrical lines, but neither very intense nor very sharp. They are nevertheless excellent lines for measurement when a sufficient exposure has been made. As the exposures required were generally much longer than is necessary for the sun, the latter spectrum was impressed at the middle time of the exposure on the arc, or, if several minutes were required for the sun, a succession of short exposures was distributed throughout the much longer arc exposure. As temperature changes in the grating have been found to be a source of appreciable errors in long exposures, even when the exposure on the sun is made at the middle time, the further precaution was taken of observing the temperature with a sensitive thermometer placed inside the grating chamber. If the temperature was found not to vary more than 0·2° Fahrenheit during a 30-minute exposure, the plate was considered safe for measurement.

The group of seven enhanced lines in the region 4508–4584 required ten minutes on the arc, and one minute on the sun, with the Michelson 5-inch grating. With the Anderson grating the lines 4924 and 5018 required fifteen minutes on the arc and three on the sun. The line 5169 could be photographed in five minutes in both arc and sun, but the fainter lines 5234, 5276 and 5316 required twenty to twenty-five minutes on the arc and four to five minutes on the sun. At the red end of the spectrum, using dyed "lantern" plates and the second order of the Anderson grating, nearly thirty minutes was necessary for the arc and two minutes for the sun.

The scale of the plates varies from 1·2 mm. per angstrom to 1·6 mm. per angstrom between 4500 and 5300, and in the second order red it varies from 0·84 to 0·89 mm. per angstrom between 6100 and 6400.

* J. Evershed, Phil. Trans. A. 201, 477.

The measures were made and reduced in the same manner as those detailed in Bulletin No. XXXVI. The residual shifts, sun — arc, after eliminating the shifts due to the earth's movements relative to the sun, are given in the table following :—

TABLE I.—SHIFTS OF ENHANCED LINES AT CENTRE OF SUN'S DISC.

	Intensity in sun.	Mean shift ☉ — arc in angstroms /10,000.	Number of plates measured.
4303·337	2	+ 39	1
4508·455	4	+ 60	
4515·508	3	+ 44	
4520·397	3	+ 3	
4522·802	3	+ 19	6
4549·642	2	+ 21	
4556·063	3	+ 10	
4584·018	4	+ 26	
4924·107	5	+ 53	4
5018·629	4	+ 136	
5169·220	4	+ 62	
5234·791	2	+ 2	4
5276·169	3	+ 63	
5316·790	4	+ 2	5
6042·315	3	+ 39	1
6456·603	3	− 19	4

This list of sixteen lines includes only those which are of sufficient intensity in the arc for accurate measurement, and which appear in the solar spectrum as single lines sufficiently separated from neighbouring lines to admit of accurate measurement. As in previous determinations when A/10,000 is taken as the unit there is a considerable variation of shift for the same lines on different plates, some lines being more consistent than others. This may be largely, but we think not wholly, due to errors of measurement.

The general result is obvious : the enhanced lines give positive shifts in every case but one. They cannot therefore represent ascending gases, as was supposed. The relation of shift to intensity found in discussing the much more numerous measures given in Bulletin No. XXXVI holds also in this series ; thus, the mean shift of the six lines of intensity 5 and 4 is + 0·0056 A, and the mean shift of the ten lines of intensity 3 and 2 is + 0·0022 A. If the displacement is interpreted as movement in the line of sight, it is clear that the iron vapour giving the enhanced lines shares in the descending movement of the iron vapour giving the arc lines, and the enhanced lines show also the retardation of this movement in the lower levels of the reversing layer.

There is one line in the list which gives an appreciable negative shift, the line 6456·603, but it would obviously be unsafe to conclude that this indicates rising movement in the sun. Besides this line there are two others, which, considering their intensities in the sun, give anomalous shifts. The line 5316 gives a practically zero shift, and the line 5018 gives an abnormally large positive shift. An attempt has been made to discover whether these three lines are shifted in the arc as in the case of unsymmetrical lines, when comparing the centre of the long arc with the short arc, and comparison spectra have been obtained of the central portion of an arc 3 to 4 mm. in length and a current strength of 4 ampères with a short arc 1 to 2 mm. in length and a current strength of 10 to 12 ampères. The enhanced lines at the centre of the longer arc are reduced to exceedingly fine lines, but in each case they are found to coincide in position with the much stronger lines due to the short arc. The test is a severe one, and in the green regions a large proportion of the ordinary arc lines of iron show very marked displacements to red or violet in the short arc, according to the nature of the unsymmetrical widening.*

It is concluded that the enhanced lines generally are symmetrical in character and well suited for sun — arc measurements. The anomalous shift of the line 5018 might be accounted for if it is assumed that this line represents a considerably higher level in the reversing layer than any other of the enhanced lines, and similarly the small shift of the line 5316 would be explained if it represents a very low level. This line however, in common with the other enhanced lines, has always been regarded as a high level line from the evidence of eclipse spectra. Anomalies of this kind of course can always be explained if a compound origin for the solar line is assumed, the wave-length being affected by an unresolved component.

* T. Royds. Kodaikanal Observatory, Bulletin No. XL.

In order to find out whether there was any relative shift between the enhanced and the ordinary lines, and also to guard against any systematic errors which might affect this particular set of plates, measurements were also made of many of the best defined and apparently symmetrical arc lines of iron. In table II we give the mean results, grouping the lines according to the colour of the spectrum where they occur :—

TABLE II.

Region.	Number of lines measured.	Mean intensity in sun.		Mean shift sun – arc in angstroms.
Blue ...	8 enhanced lines	3·0	+	0·0028
	7 arc lines	3·9	+	0·0039
Green ...	6 enhanced lines	3·7	+	0·0053
	20 arc lines	3·7	+	0·0053
Red ...	2 enhanced lines	3·0	+	0·0010
	10 arc lines	6·0	+	0·0041

This table shows an essential agreement of shift between the enhanced lines and the arc lines, such differences as occur being accounted for by differences of mean intensity, and by the anomalous shift of one of the two red lines.

The enhanced lines of iron in the sun give therefore no evidence of a radial circulation of the solar gases, nor of any relative movement compared with the arc lines. An upward compensating movement is of course not excluded by this result; it may be that the hotter ascending gases do not give appreciable absorption lines, the emission being of the same intensity as the background of continuous spectrum. The enhanced lines in eclipse spectra may in fact represent the ascending gases, while the enhanced absorption lines in the Fraunhofer spectrum, in common with the arc lines, represent the falling gases. If this were so, each enhanced absorption line would have an emission line on its more refrangible side when observed at the centre of the sun's disc; but it would be difficult or impossible to detect this if it were nearly equal in intensity to the continuous spectrum.

The question whether there is such a radial circulation of the solar gases, and whether the general movement of recession is radial to the sun or radial to the earth, can probably be determined by observations made across the disc from the centre towards the limb, since if the movement is radial to the sun, and part of a general circulation, the line-of-sight component of this motion should decrease to zero at the limb, the wave-lengths of the lines decreasing proportionately with the cosine of the angular distance from the centre. Observations of this kind are now being made, and the results will be published in a subsequent Bulletin.

THE OBSERVATORY, KODAIKANAL,
29th April 1915.

J. EVERSHED.
A. A. NARAYANA AYYAR.

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Kodaikanal Observatory.

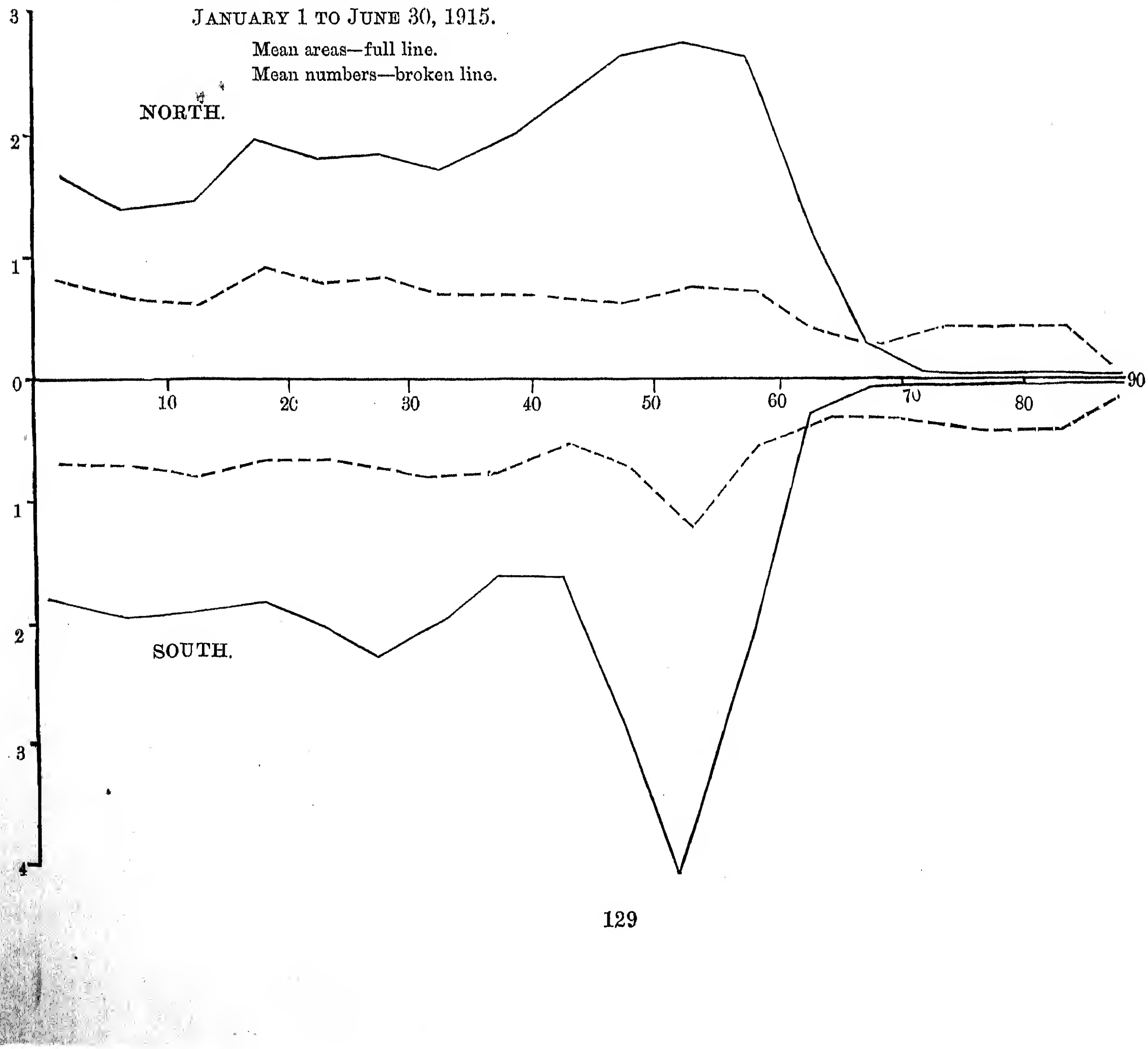
BULLETIN No. XLVII.

SUMMARY OF PROMINENCE OBSERVATIONS FOR THE FIRST HALF OF THE YEAR 1915.

Visual observations of prominences were practically confined to displacements of the hydrogen lines and to metallic prominences and the photographs were relied on for position angles, heights, and areas of prominences.

The distribution of prominences observed and photographed during the half-year ending June 30, 1915, is represented in the accompanying diagram. The full line gives the mean daily areas, and the broken line the mean daily numbers for each zone of 5° of latitude. The ordinates represent tenths of a square minute of arc for the full line and numbers for the broken line. The means are corrected for partial or imperfect observations, the total of 173 observing days being reduced to 163 effective days.

MEAN AREAS AND MEAN NUMBERS OF PROMINENCES.
JANUARY 1 TO JUNE 30, 1915.



The mean daily areas and daily numbers corrected for partial observations are as follows :—

	Mean daily areas (square minutes).	Mean daily numbers.
North	2·59	10·83
South	2·68	10·60
Total ...	5·27	21·43

The mean daily area is the largest recorded since 1908. Compared with the previous six months the mean areas have increased 59 per cent, and the mean numbers 19 per cent. The distribution in prominences is similar to that obtaining last year; there is a belt of great activity between 45° and 55° beyond which the activity diminishes towards the poles and remains nearly constant to the equator.

The monthly, quarterly and half-yearly frequencies and the mean height and extent are given in the following table. The frequencies are derived from the number of effective days.

Abstract for the first half of 1915.

Month.	Number of days of observation.		Number of prominences.	Mean daily frequency.	Mean height.	Mean extent.
	Total.	Effective.				
1915.					″	°
January	28	27	557	20·6	32·3	3·04
February	28	27	581	21·5	29·3	3·29
March	31	30	651	21·7	30·1	4·28
April	30	30	655	21·8	31·7	3·68
May	31	30	637	21·2	31·5	3·63
June	25	19	431	24·8	31·1	2·99
First quarter ...	87	84	1789	21·3	30·5	3·57
Second quarter ...	86	79	1723	21·8	31·5	3·49
First half-year ...	173	163	3512	21·5	31·0	3·53

The steady increase recorded during 1914 has therefore been maintained during the first half of 1915; there is however now an increase in frequencies as well as in areas; the mean height is the same as in the second half of 1914 but there is an increase of 39 per cent. in the mean extent.

Distribution east and west of the sun's axis.

Prominence numbers show a slight and areas a large decrease in the percentage at the eastern limb; in areas there is a preponderance at the western limb which was most marked during May and June. The distribution was as follows :—

1915 January to June.	East.	West.	Percentage east.
Numbers observed	1766	1744	50·31
Total areas in square minutes of arc	4183	4410	48·68

Metallic prominences.

The following metallic prominences were recorded in the half-year :—

TABLE I.—LIST OF METALLIC PROMINENCES. JANUARY—JUNE, 1915.

Date.		Hour I.S.T.	Base.	Latitude. North.	Latitude. South.	Limb.	Height.	Lines reversed.
1915.		H. M.	°	°	°		″	
January	1	8 54	2	22	...	W	15	D_1, D_2, 5316·8, b_1, b_2, b_3, b_4, 4924·1.
	3	8 34	...	20	...	W	25	D_1, D_2, b_1, b_2, b_3, b_4, bright over 5°.
	6	8 9	19	21·5	...	W	125	D_1, D_2, b_1, b_2, b_3, b_4. 6677 and 5316·8 very bright at base.
	13	9 30	5	19·5	..	W	25	D_1, D_2, b_1, b_2, b_3, b_4, 5316·8.
	15	8 59	4	53	...	E	40	D_1, D_2, b_1, b_2, b_3, b_4.
		10 8	...	26	...	E	...	Two bright points in chromosphere. D_1, D_2, b_1, b_2, b_3, b_4, 6677, 7065 bright, last two being conspicuous.
February	7	9 5	6	23	...	E	60	D_1, D_2, b_1, b_2, b_3, b_4.
	8	9 30	4	25	...	E	55	D_1, D_2, b_1, b_2, b_3, b_4, 6677, 5316·8, 5283·8 prominence seen in 6677 and D's and b's.
	9	8 48	...	10	..	E	25	D_1, D_2, b_1, b_2, b_3, b_4, 5316·8, 6677.
	13	9 10	3	...	21·5	W	50	D_1, D_2, b_1, b_2, b_3, b_4.
	14	8 45	...	...	26	W	60	D_1, D_2, b_1, b_2, b_3, b_4. 6677, 5316·8, 4924·1, 5283·8, 5281·9.
	19	9 4	...	...	18	W	10	D_1, D_2, b_1, b_2, b_3, b_4, 6677, 5316·8, 4924·1, 5535·06.
	21	8 22	5	20·5	...	W	30	D_1, D_2, b_1, b_2, b_3, b_4, 6677, 5535·06, 5316·8, 5361·8, 5284·3, 5276·2 very bright.
	26	9 2	12	...	23	E	135	D_1, D_2, b_1, b_2, b_3, b_4.
March	8	8 42	19	22·5	...	W	45	D_1, D_2, b_1, b_2, b_3, b_4, 6677, 5316·8, 4924·1, whole prominence seen in D's and b's.
	14	8 33	...	...	19·5	E	...	D_1, D_2, b_1, b_2, b_3, b_4.
	18	9 20	...	17·5	...	W	60	D_1, D_2, bright near base.
April	2	8 20	7	23·5	...	E	45	D_1, D_2, b_1, b_2, b_3, b_4, 5316·8.
	4	8 45	9	24·5	...	W	25	D_1, D_2, b_1, b_2, b_3, b_4, 5316·8.
	11	8 40	8	15	...	W	30	D_1, D_2, b_1, b_2, b_3, b_4, 5316·8, 4924·1.
	12	8 26	19	30·5	...	W	60	D_1, D_2, b_1, b_2, b_3 b_4, 5316·8, 5276·2, 4924·1, 6677, 7065. Prominence was 20″ high at +31° W. in D's and b's.
	17	9 0	3	...	20·5	W	15	4924·1, 5018·6, b_1, b_2, b_3, b_4, 5188·9, 5197·8, 5204·8, 5206·2, 5208·7, 5226·7, 5227·4, 5234·7, 5265·0, 5269·7, 5276·2, 5284·2, 5316·8, 5363·0, 5535·0, D_1, D_2, 6677.
	27	8 20	13	13·5	...	E	20	D_1, D_2, b_1, b_2, b_3, b_4, 5316·8.
May	8	8 30	8	17	...	W	105	D_1, D_2, b_1, b_2, b_3, b_4.
	20	7 55	...	.	51·5	W	30	D_1, D_2, b_1, b_2, b_3, b_4, bright at base.
	21	8 57	...	20	...	E	55	D_1, D_2, b_1, b_2, b_3, b_4, 5316·8, 5276·2, 6677, 7065, 5016. Prominence seen over a height of 25″ in b_1, b_2 and b_3, and over 15″ in the other lines.
	22	8 52	...	18	...	E	60	Two bright portions at these points were visible in D_1, D_2, b_1, b_2, b_3, b_4, 6677 and 7065.
		52	...	25	...	E	60	
June	4	8 35	...	17	...	W	60	D_1, D_2, b_1, b_2, b_3, b_4, 6677, 7065, visible over 25″ in the first five lines.
	6	8 45	...	18·5	...	W	...	D_1, D_2, b_1, b_2, b_3, b_4.

Displacements of the hydrogen lines.

Particulars of these disturbances are given in the following table :—

TABLE II.—DISPLACEMENT OF THE C LINE IN PROMINENCES. JANUARY—JUNE, 1915.

Date.		Hour. I.S.T.		Latitude.		Limb.	Amount of displacement.			Remarks.
				N.	S.		Red.	Violet.	Both ways.	
1915.		H.	M.	°	°		Å.	Å.	Å.	
January	1	8	54	28		W	2	2		
	2	8	48	50		E		Slight		
			48		59·5	W	Slight			
			55	83·5		W		0·5		
	3	8	44		65	W	2			
			34	20		W	Slight			
			25	76·5		W		Slight		At top of prominence.
	4	9	2		21·5	E		0·5		No prominence.
			12	22		W			Slight	
	6	8	44	37·5		W	Slight at top	Slight at base		1·5 Å to red at top at 9^h 25^m.
			44	28		W	2			2 Å to red and 2Å to violet at 9^h 52^m ; about 3 Å to violet over the streamers at 8^h 57^m; 4 Å to red at 9^h 4^m. At 9^h 24^m top of streamers displaced to red for about 1·5 Å, bottom to violet.
	7	9	5		79	W	0·3			No prominence.
			10		30	W		Slight		Over whole prominence.
			17	28·5		W		3		
	9	8	30		23	W	1			No prominence.
	10	10	10	73·5		E	0·2			Do.
	12	8	53		38	E	1·5			
			50		70·5	E		1		
	13	9	20	16·5		W		2·5		At top of prominence.
			30	20		W	1·5			
	14	9	20	18		E	1			At base of prominence.
			45		8·5	W	2			
	15	10	3	76		E	Slight			
		8	59	53		E	Slight at base	Slight at top *		* At + 51° E. and + 56° E.
		10	8	25·5		E	Slight	0·5		At two different points in chromosphere.
			11	18·5		E	Do.			
			11	15·5		E	Do.			
			20		35·5	E	Do.			No prominence.
		9	53		81·5	W		0·5		
	18	8	42		44	E		Slight		At base of prominence.
	23	8	25	80·5		E	Slight			
			25	78·5		E		Slight		
			42	37		E		0·5		At base of prominence.
			45		5·5	E	Slight	0·5		No prominence.
	26	8	45	50		W	Do.			
			48	57		W	0·3			
	28	8	45		65	W	0·5			At base of prominence.
	29	8	50		75	E			Slight	
	30	9	0		15·5	E		1		
			0		19·5	E		1		
	31	8	30		20·5	E		1·5		
			30		27·5	E		1·5		
February	1	8	41		22	E		Slight		
			24	29		W	Slight			At top.
	3	8	29		4·5	E		0·3		Do.
			27		49	E		0·5		
			27		53	E	Slight			
			45	75·5		W		0·4		Amount 1·0 Å at 8^h 46^m.
	4	8	35	83		E		0·5		
		9	18		13·5	E	0.5			
		8	51		27	W		0·2		
			44	65		W		0·5		
	5	10	50		13·5	E			0·4	
		11	0		57·5	W		Slight		
	6	8	59	34		W		0·5		
	7	9	2	23		E		2		
	8	9	30	25		E	3			
			2		54·5	E		1		

Date.		Hour. I.S.T.		Latitude.		Limb.	Amount of displacement.			Remarks.
				N.	S.		Red.	Violet.	Both ways.	
1915.		H.	M.	°	°		Å.	Å.	Å.	
February	9	8	50	43		E		0·3		At top (75″).
			40	10		E	0·5	1		
			32		45·5	E		2		At top (15″).
	11	8	53	61		E	Slight			
			56	28·5		E	Do.			
			37	66·5		W	Do.			Gone at 8h 38m.
	12	9	42	61·5		E	Do.			
			35		61	E	Do.			
	13	9	10		21	W	1 at base	Slight at top		Slightly changing in shape and amount.
		8	35	22·5		W	0·5	1		
	14	8	40	55		E		Slight		
			35	4·5		E		Do.		
			35	2·5		E		Do		
			45		26	W	0·5	0·5		
			58		21	W	3			Displaced portion detached from C line at 8h 59m.
		9	4	21		W	1·5			At top (about 25″).
	15	8	30		17·5	E		Slight		
	16	8	25	82·5		E	0·2			
	19	8	36		18	W	1	1		1·5 Å to violet at 8h 38m.
	20	9	2	63		E	Slight			
		8	58	6·5		E		0·2		
			58	12		E	0·2			
			48		49·5	W	Slight			
	21	8	22	20·5		W	0·5			
			20	29		W		Slight		At top (30″).
	22	9	12		32·5	E	2			
	25	8	40	35·5		E	0·5			
			38		25	W	Slight at base			
March	2	10	39	47		E		0·5		
	4	9	13	82·5		E	0·5	Slight		
		9	17	73		E		4		Amounts much smaller at 9h 19m.
			17	72		E	8			
			17	69		E	Slight			
		8	59	65·5		E	Do.	0·5		
			41		51	E	Do.			
		9	3		25·5	W	Do.			
	5	8	40	57		E		Slight		
			40	55		E	Slight			
			40		30·5	E		1·5		
	7	9	16	82·5		W		1		
			4	78		E			Slight	
			18	61		E	1 at base			
		9	0	28·5		E			Slight	
		8	45		15	E		Slight		
			44		30	E	Slight			
			42		60	E		Slight		
			38		68	W		0·5		
		9	11	18		W		2		At top (25″).
			14	36·5		W		1·5		
		8	45	26		W	0·5			
	8	8	42	30·5		W	0·5	2		
	9	8	25		50·5	E		1		At top (40″).
			46		1	W		1·5		
	10	8	59	64		E		Slight		
			55		52	W		1		At top (50″).
		9	4	32·5		W	Slight			At top (30″)
	11	8	38	82·5		E	0·5			
			38	80		E		Slight		At several places { Rapidly changing.
			30	46		E	0·3			At 8h 33m 0·3 Å to violet.
		9	3	27		E		Slight at base		
			27		70·5	E	0·5			} Gone at 9h 30m.
			27		72·5	E		1		
		8	55		34·5	W			1 at base	
			52		5	W			Slight	
			49	13·5		W		Slight		At top (60″).
			43	51·5		W		1		
			43	54·5		W		1		
			40	79·5		W		Slight		

Date.		Hour. I.S.T.		Latitude.		Limb.	Amount of displacement.			Remarks.
				N.	S.		Red.	Violet.	Both ways.	
1915.		H.	M.	°	°		Å	Å	Å	
March	13	8	30		52	W	Slight			At several points.
			38		21	W	Slight at base			
	14	8	33		19·5	E		1		At two points.
			24		22	W		Slight at base		
			21		4·5	W	0·5			
	16	8	40	22		E		Slight		
			32		60	E	Slight			
			32		58	E		Slight		
			52	17		W	Slight			
	18	8	26	75·5		E		0·5		In two places.
			8	42		E	1			
			58		78·5	W		Slight		
			14		54	W	Slight			
	19	8	50	78		E		2		At top (40″). Nothing at 8h 54m.
			58	14		E		1 at base 2 at top		
			58		47·50	W	0·3			
			58		62	W	0·3			
			36	15·5		W			Slight	
			34	54		W		0·4		At top (30″).
	20	8	20		45·5	E		1·5		
	21	8	4	28		E	Slight			
			25		52·5	W	Slight at top	Slight at base		
	23	8	21	33		E			Slight	
			27		36	W	0·5			
			24	42·5		W	Slight at base			
	24	8	30		53·5	E		Slight at base		
	25	8	37	13		E		Slight		Over 3°.
			33		21	E	0·5			
			28		47·5	E		1		
			53	70·5		W			Slight	
	26	9	5	22		W		2·5		At top (45″).
	27	8	56		55	W	2			At top (30″).
			32	27		W		Slight		
	29	8	42	34·5		E		Do.		
April	1	8	40		48	E	0·5 at top	0·5 at base		
		9	2	43		W		Slight		
	4	8	30	62		E		Do.		
			29	55		E	1			
		9	4		25	E		Slight		
			7		72	E		Do.		
		8	56		41·5	W		1		
			47	19		W	0·5 at base			
			38	48·5		W	0·5			
			34	78		W	3			
	5	8	27	32		E		1		
			28	4		E			0·5	
			39		70	E			Slight	
			41		32·5	W			Do.	
			17		74·5	W		0·5		
			36	30·5		W		1		
	6	8	33	56·5		E	Slight at base			
			37	49·5		E		0·5		
	7	8	40	42		E		Slight at base		
			36		62	E			Slight	
	8	8	37	56		E	Slight at base	1		
	10	8	59	56		E		2		
			57	44·5		E		0·5		
			57	42·5		E	0·5			
	11	8	17		59	W		1		
			38		14	W	Slight at base	Slight at top		
			20	15		W	1			At top of prominence C displaced to red by amount ranging from 3 Å to 4 Å from + 17 W to + 27 W; C was also displaced to violet for 2 Å at + 19 W; no displacement to red at 9h 2m.

Date.		Hour. I.S.T.		Latitude.		Limb.	Amount of displacement.			Remarks.
				N.	S.		Red.	Violet.	Both ways.	
1915.		H.	M.	°	°		Å.	Å.	Å.	
April	12	9	0	18		W	Slight	1		
			0	16		W	Do.			
		8	22	52·5		W		0·3		
	13	8	24	60		E	Slight			
			18		19	E		Slight		
			33	78·5		W	0·3			
	14	8	26	62		E	0·5			
			24	60		E		Slight		
			33	7·5		W		0·5 at base		
	16	9	13		57·5	W		Slight		
			28		31	W	Slight			Over upper half of prominence (25″).
	17	8	38		22	W	0·5			F displaced 1 Å to red at 9h 0m.
			38		19	W		Slight		
	18	8	20	60·5		E		0·3		Over whole prominence.
			13		50·5	E	Slight			
			8		60·5	W		Slight		
	19	8	40		22·5	E		2		
			42		25	E	1			
		7	58	84·5		W	0·2			
	20	8	20		50	W	Slight			
			40	67·5		E		0·5		
	21	8	50		63·5	E	2·5	2 at top		Disappeared at 9h 1m.
	22	8	10	76·5		E		Slight		
			39	23·5		E	Slight			
			41	19		E	Do.			
			46		27·5	E	1 over upper half of prominence.	1 near base		
			52		67	W	1			
			30		8	W		0·5		
			28	19		W	Slight			
			20	59·5		W		1		
			17	72		W		0·5		
			15	75·5		W		0·5		
	23	8	22		24	E		Slight		Over the streamer.
			30		51	W		0·5		
			35	21		W		1		Over the whole height (35″).
			39	69·5		W		1		
			24	75		E	1			Gone at 8h 25m.
			21	72		E		1		
	25	8	52		30	E	Slight			Over the streamer.
			33	21		W			Slight	
			30	49·5		W		1		
	26	8	40	68·5		E		Slight		
			31	53		E	Slight			
			30	37		E	1			
			28	20·5		E		1·5		
			28	16		E		Slight		
			20		19	E	1	1		
			30	2		W	Slight			
	28	8	30		27	E		1·5		
			35		18	W		1·5		
	30	8	42	72·5		E	0·5			
			0	71·5		E		1·5		
			38	48		E			0·5	
			38	46		E		0·5		
		9	1	21		E	0·5	1		
			10		75·5	E	Slight			
			12		81·5	W	0·5			
			47	61		W	0·5			
May	2	8	9	55		E	Slight			
	3	8	44	77·5		E	Do.	1		
	6	8	47	62·5		W		1		0·5 Å both ways at 8h 45m.
	7	8	27	80		E	Slight	on upper part of prominence. 1 at base		At two points. Nothing at 8h 40m.
			44	23·5		E				

Date.	Hour. I.S.T.		Latitude.		Limb.	Amount of displacement.			Remarks.
			N.	S.		Red.	Violet.	Both ways.	
1915.	H.	M.	°	°		Å	Å	Å	
May 7	8	47	16		E		1		Northern end
		47		8	E	Slight			
		54		44	E	0·5 southern part of prominence.	0·5 northern part of prominence.		
		59		86	W	Slight	Slight		
		35		67	W		Do.		
	8	28		63	E		Do.		
		23		78	W	Slight			
		42	14·5		W		0·5		
10	8	27	70		E		1		Over the whole of northern prominence.
		33	16		W	Slight			
13	11	0		35	E		Slight		
14	10	8		35·5	W	Slight			
		22		34	W		0·5		
		20	49		W		0·5		
17	8	51	60·5		E	Slight			
		45		35	W		1		
	9	2		73·5	W		1		
	8	42		2·5	W	1			
20	8	28	26		E		1·5		
		48	17·5		E		1		
		39		68	E	Slight			
		38		82	E		Slight		
		28		56	W		Do.		
21	8	56	77		E	Slight			
		57	25		E	1			Over the whole height (55″).
	9	5		8	E		Slight		
		7		2·5	E	Slight at top.	Slight at base		
		11		52·5	E	0·5			
		13		73·5	W		Slight		
	8	49		50·5	W	0·5			
		43	11·5		W				
22	8	50	16		E	0·5	1		Over the whole height (60″).
		48	3·5		E	0·5			
		44		52·5	E		0·5		
		42		60·5	E	Slight			
		39		77·5	W	1			
	9	5	17		W		1		
23	8	57	20·5		E	1			Over the streamer.
	9	3		35	E		Slight		
		6		80	W		1·5		
	8	25	35–39		W	4 over whole height.			Slightly displaced to violet over the rest of the arch.
24	9	15	85·5		E	Slight			
		1	88		E	2·5			Nothing at 9h 15m.
	8	55		35	E	Slight			
		52		49	E		0·5 at base.		
		46		68·5	W		Slight		
		45		55·5	W	Slight			
	9	11	16–22		W	Do.			
27	8	35	68		E		1		
28	8	43	85		E			Slight	
		35		56	E		Slight		
		34		71	E		Do.		
		48		28	W	Slight			
		50		17	W		0·5		
		54	56		W		0·5		
		55	86		W		Slight		
31	8	58	40		E	Slight	Do.		
		52		65·5	W		0·5		
		45	17		W	Slight			
		43	61·5		W		Slight		
June 2	8	48		57	E		Do.		At two points at the base.
4	8	52		78	W	Slight			

Date.		Hour. I.S.T.		Latitude. N.	Latitude. S.	Limb.	Amount of displacement. Red.	Amount of displacement. Violet.	Amount of displacement. Both ways.	Remarks.
1915.		H.	M.	°	°		Å.	Å.	Å.	
June	4	8	35	22·5		W		0·5		
			28	20		W		1·5		
			28	24		W		1		
	6	8	37	85·5		E		Slight		
			39		55	W		Do.		
			43	18·5		W	2	1		Only slightly to violet and nothing to red at 8h 45m.
	8	8	25		40·5	E		Slight		
	11	8	42		27·5	E		0·5		Gone at 8h 44m.
	12	10	5	2		E		Slight at base.		
	14	8	52	19·5		E	1·5			
			38	48		W	Slight			
	18	8	50	52·5		E	0·5			On the detached part of prominence.
			48	14·5		E	Slight			

There was a large increase in the number of displacements compared with the previous half-year. In the northern hemisphere there were 184, in the southern 141 ; in the eastern hemisphere there were 178, in the western 147. One hundred and eighty-five displacements were to the violet, one hundred and fifty-two to the red and sixteen both ways simultaneously.

Between 0° and 30° of latitude there were one hundred and twenty-five displacements, between 31° and 60° one hundred and one, and between 61° and 90° ninety-nine. It is noteworthy that during the past spot minimum the greatest number occurred between 61° and 90°.

Reversals and Displacements of the C line on the Disc.

Two hundred and eleven reversals of the C line, sixty-six darkenings of the D_3 line, and one hundred and five displacements of the C line were observed near spots. This is a large increase on the previous half-year. The following table gives their distribution east and west of the central meridian :—

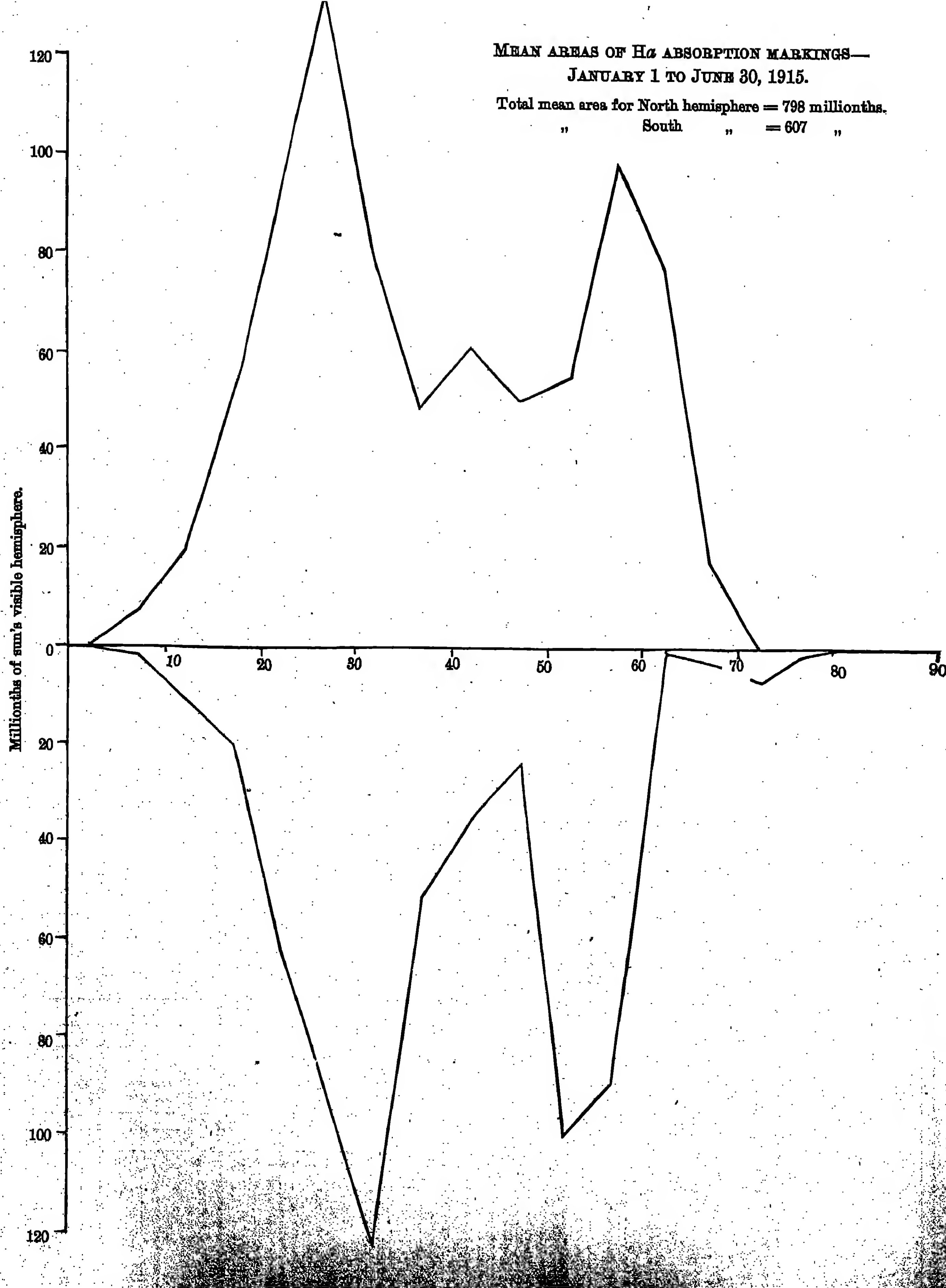
	East.	West.
Reversals of C near spots	106	105
Darkenings of D_3	37	29
Displacement of C	51	54

There was a large preponderance of displacements to the red, 72 being towards the red as against 23 to the violet.

Prominences projected on the Disc as Absorption Markings.

The grating spectroheliograph for photographing the absorption markings in hydrogen light was in regular use during the six months. Photographs were obtained on 123 days which were counted as 105 effective days. There has been a large increase in the number of absorption markings observed ; this increase began in the second half of 1914. The mean daily areas in millionths of the sun's visible hemisphere corrected for fore-shortening and for imperfect observations and the mean daily numbers are compared in the following table with the recent half-years for which complete information is available :—

	1912 Jan.—June		1912 July—Dec.		1913 Jan.—June		1913 July—Dec.		1915 Jan.—June.	
	Areas.	Numbers.	Areas.	Numbers.	Areas.	Numbers.	Areas.	Numbers.	Areas.	Numbers.
North	81	0·39	56	0·32	44	0·24	24	0·28	768·2	3·8
South	252	1·07	382	1·28	84	0·56	36	0·30	607·4	3·4
Total ...	333	1·46	438	1·60	128	0·80	60	0·58	1375·6	7·2


MEAN AREAS OF Hα ABSORPTION MARKINGS—
JANUARY 1 TO JUNE 30, 1915.
Total mean area for North hemisphere = 798 millionths.
" South " = 607 "
Millionths of sun's visible hemisphere.
120
100
80
60
40
20
0
10
20
30
40
50
60
70
80
90
20
40
60
80
100
120

Besides the usual maximum between 50° and 60° corresponding with the prominence maximum there is a pronounced maximum near 30° both north and south due to prominences in sunspot latitudes; this maximum occurs at about 10° higher than the spot maximum, but the activity tends to vanish towards the equator in agreement with spot activity. The occurrence of a prominence maximum near 50° and almost complete absence of increased activity near 30° is not due to any essential difference in the nature of dark Hα markings in these two regions, but the predominence of the prominence maximum at 50° is well accounted for by the two facts that in these latitudes the Hα markings form a belt approximately parallel to the equator and that the speed of rotation of the sun is slower; both of these facts make the prominence due to an Hα marking in these latitudes endure for a larger number of days.

There was a preponderance of Hα markings on the eastern side of the central meridian, the percentage east being 56·50 in areas and 54·62 in numbers.

THE OBSERVATORY, KODAIKANAL,
18th August 1915.

T. ROYDS,
Assistant Director.

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BULLETIN No. XLVIII.

ANOMALOUS DISPERSION IN THE SUN,

By T. ROYDS, D.Sc.

In a recent number of the Astrophysical Journal Dr. Sebastian Albrecht claims to demonstrate the effect of anomalous dispersion in the sun.[1] Employing the test of the mutual influence of neighbouring dispersion bands he has obtained the solar displacements of the iron lines and finds that those lines which have a close companion on one side or the other are displaced in the sun in the direction predicted by the theory of anomalous dispersion. According to Albrecht's results lines with a companion on the red side are, on the average, displaced to the violet in the sun by 0·007 A, for a mean ratio of intensities of 3 : 4 and a mean separation of 0·24 A ; those with a companion on the violet side are displaced to the red by 0·005 A, for a mean ratio of intensities of 8 : 9 and a mean separation of 0·21 A. There is, therefore, a relative shift of 0·012 A between the two groups of lines.

The method by which Albrecht has arrived at the solar displacements must, in my opinion, be regarded with suspicion. The displacements were deduced by comparing the solar wavelengths determined by Rowland[2] with the wavelengths in the iron arc determined in the laboratory. The process was to plot the differences between the solar wavelengths in Rowland's Table and the arc wavelengths and to draw a mean curve through them to represent the systematic errors of Rowland's table ; the residuals between the actual difference for each line and the curve were regarded as the relative solar displacements of the iron lines. There are sufficient examples in the history of spectroscopy to show the danger of attempting to derive displacements from differences in wavelength tables. Certainly one would expect this to be so in comparisons with Rowland's Table. Rowland claims only an accuracy of ± 0·01 A in his standards,[3] and there are reasons to believe that this is an under-estimate of the errors. Kayser thinks that quite apart from the mistake in the absolute values, the error is generally about ± 0·02 A,[4] and that the systematic error cannot be determined within ± 0·01 A.[5] It therefore seems to me that residuals generally less than 0·01 A cannot have much real meaning and I think the comparison with displacements given in this paper shows that even the average of a fairly large number of residuals has little significance.

The solar displacements can be obtained in a direct and simple manner by comparing the solar and arc spectra simultaneously on the same plate and measuring directly the shift between the two ; after eliminating the motion of the earth relative to the sun, the true sun-minus-arc displacement is given. There can be no cavil against this procedure and the superiority, if not absolute necessity, of direct comparison methods in order to obtain displacements need not be elaborated here. If, then, Albrecht's residuals, containing perhaps innumerable unknown errors, evidence a real relative shift of 0·012 A between solar lines according to the side on which the companion lies, it is clear that the direct method of observing displacements, free from the errors involved in wavelength determination, must render the shift unmistakeable and free from doubt.

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[1] S. Albrecht, Astrophysical Journal, XLI, 333, 1915.
[2] Rowland, Preliminary Table of Solar Spectrum Wavelengths.
[3] Rowland, Physical Papers, p. 557.
[4] Kayser, Handbuch der Spectroscopie, Vol. VI, p. 887.
[5] Kayser, Handbuch der Spectroscopie, Vol. VI, p. 888.

The sun-minus-arc displacements of the iron lines have been measured by various observers. Using the determinations of Evershed and Royds,[1] the sun-minus-arc displacements were compared with Albrecht's residuals for all lines common to their and Albrecht's lists. As all the data on which this comparison is based has already been published in the papers referred to it will suffice to list the lines used. They are given below :—

TABLE I.

Fe lines with companion to the red.		Fe lines with companion to the violet.	
3705·708	4707·457	3680·069	4592·840
3735·014	4938·997	3737·281	4787·003
4191·595	4957·480	3887·196	4789·849
4210·494	5005·896	3895·808	4872·332
4337·216	5107·619	3969·413	4957·785
4454·552	5139·427	4132·235	5006·306
4461·818	5195·113	4134·840	5098·885
4637·685	5328·236	4144·038	5107·823
4679·027		4191·843	5139·644
		4227·606	5167·678
		4233·772	5227·362
		4308·081	5371·734
		4315·262	5447·130
		4427·482	5455·834
		4531·327	5615·877

The sun-minus-arc displacements were obtained using an arc in air at a pressure of three-quarters of an atmosphere, whilst Albrecht has made use of wavelengths in the arc in air generally at atmospheric pressure, reducing them to wavelengths at half an atmosphere which he supposes to approximate to the solar pressure.[2] It is immaterial for the present purpose to whichever of these pressures the arc wavelengths are reduced, for the *relative* shift (column 4 in Table II) of the two groups of iron lines remains practically unaffected.

The means for the iron lines listed in Table I are given below in Table II.

TABLE II.

Relative Shift of the two groups of Iron Lines.

	—	17 Fe lines with companion to red.	30 Fe lines with companion to violet.	Relative shift.
Straight means.	Albrecht's residuals [3]	— 0·0059 A	+ 0·0052 A	+ 0·0111 A
	Sun-arc displacements	+ 0·0039 A	+ 0·0068 A	+ 0·0029 A
Weighted means.	Albrecht's residuals [3]	— 0·0086 A	+ 0·0079 A	+ 0·0165 A
	Sun-arc displacements	+ 0·0032 A	+ 0·0079 A	+ 0·0047 A

The first section of the table gives the straight means and the last section the weighted means according to the weights assigned by Albrecht to each line. It is seen that whilst Albrecht's indirect method gives a relative shift of 0·0111 A (straight mean), or 0·0165 A (weighted mean), the direct method gives values only one quarter of these amounts but in the same direction. Consequently the results of Albrecht showing a large effect of anomalous dispersion in the sun are mainly, if not entirely, fictitious. It should be pointed out that the lines used in the above comparison are not those least favourable to Albrecht's conclusions since the relative shift according to the residuals is not less for the lines used than that obtained by using the whole number of lines in his tables, which was 0·009 (direct mean), or 0·0160 (weighted mean).

[1] Kodaikanal Observatory Bulletin, Nos. XXXVI, XXXVIII and XXXIX. The experiments with the short arc have not been taken into account.

[2] This value for the solar pressure results from ignoring the density effect. See Kodaikanal Observatory Bulletin, No. XXXVIII.

[3] Albrecht's signs have been reversed to agree with the direction of the supposed displacement.

There is, however, even in the sun-minus-arc displacements a small relative shift amounting to 0·0029 A (direct mean), or 0·0047 A (weighted mean) in favour of the anomalous dispersion theory. Whether this small amount has any real significance is doubtful. It is larger than the shift to be expected from the difference in the average solar intensity of the two groups of lines, but so small a shift unless based on a large number of measurements cannot be regarded as independently establishing a physical property of the sun's atmosphere.

Although Albrecht's complete discussion of the systematic differences between Rowland's Table and the International System has not been published, it is already possible to enunciate some objections to the procedure on which his recent article depends. In reducing the arc wavelengths for comparison with solar lines Albrecht has ignored all solar conditions producing changes in wavelength except pressure. Firstly and most important, there are at the centre of the sun's disc, Doppler displacements discovered by Evershed [1] which are not constant but vary from line to line according to the effective depth of its origin in the reversing layer. How far this fact has affected the curve of systematic errors it is impossible to say without a detailed examination. Secondly, it has been shown that lines widened unsymmetrically in the arc are displaced in the sun relative to the symmetrical lines in a way which cannot be explained on pressure hypotheses. [2] However, this fact probably does not seriously affect the *relative* shift of the lines with close companions, as was pointed out previously.

Again, Rowland's exact procedure in deriving the wavelength of a particular solar line is not definitely known. In the extreme case of lines unresolved in the solar spectrum it is manifestly impossible to obtain the exact solar wavelengths of the components. Yet these lines are assigned high weights by Albrecht. One can only conceive that Rowland has in these cases determined the arc wavelengths, applying an uncertain correction to reduce to the solar standards. If so, how is it possible to attach any significance to Albrecht's residuals for such lines ? If Rowland's values for unresolved lines really represented their true solar values the relative separation of the cyanogen lines between λλ 3872 and 3880 in Rowland's Table and in the arc would be an excellent test for anomalous dispersion in the sun, since the lines are very close together, of equal intensity and not complicated by pressure shifts ; but since we do not know what Rowland's values really represent it seems to me useless to make the comparison.

There are many difficulties in the way of accepting claims to demonstrate the existence of anomalous dispersion in the sun. It has been pointed out that if a Fraunhofer line is really enveloped in a dispersion band there should be, where the effect is expected to exist, a dissymmetry of the two edges of the line, producing a distortion which is not to be seen in the sun. [3] Further, Albrecht claims to show that the mutual influence of Fraunhofer lines exists when the separation amounts to as much as 0·5 A. The limit of any dispersion band present in the solar spectrum must extend less than 0·1 A from the centre of the line for the majority of lines and less than 0·05 A for many ; it is difficult to see how two such lines brought to 0·5 A apart could possibly influence each other.

The following conclusions are drawn from the above :—

(1) The residuals between Rowland's Table and arc wavelengths cannot be trusted to represent relative displacements.

(2) When the actual sun-minus-arc displacements are substituted for Albrecht's residuals the relative shift between the two groups of solar lines having a close companion on one side or the other is too small to establish anomalous dispersion in the sun.

I wish to express my indebtedness to the Director, Mr. J. Evershed, F.R.S., for many suggestions.

THE OBSERVATORY, KODAIKANAL,
29th October 1915.

T. ROYDS,
Assistant Director.

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[1] Evershed, Kodaikanal Observatory Bulletin, No. XXXVI.
[2] Royds, Kodaikanal Observatory Bulletin, No. XXXVIII.
[3] Evershed, The Observatory, 37, 388, 1914.

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Kodaikanal Observatory.

BULLETIN No. XLIX.

ON THE CHANGE OF WAVE-LENGTH OF THE IRON LINES IN PASSING FROM THE CENTRE OF THE SUN'S DISC TO THE LIMB,

By J. EVERSHED, F.R.S., AND T. ROYDS, D.Sc.

Following on our researches on the displacements of the solar iron lines at the centre of the sun's disc and at the limb, we now give the results of measures of the change of wave-length of some selected lines in passing from the centre of the disc to the limb.

It has been shown in Kodaikanal Observatory Bulletin No. XXXIX that if we select certain lines of iron which in the arc spectrum are not subject to the density shift near the negative pole, and compare them with the same lines at the centre of the sun's disc, a total of 45 lines gives an average displacement of + 0·0094A, whilst near the limb the displacement of the same lines is + 0·0150A, showing a difference of shift, or increase of wave-length, in passing from the centre to a point about one-thirtieth of the radius inside the limb of 0·0056A. The question whether this increase occurs gradually or suddenly as the limb is approached is a crucial one with regard to the hypothesis which ascribes the limb shift to a difference of pressure between the effective regions of absorption at the centre and at the limb; and the form of the curve representing the change of wave-length between centre and limb should also throw light on the question whether the redward shift at the centre of the disc is due to a downward movement radial to the sun.

In many individual cases the difference of wave-length between centre and limb is much greater than that indicated above, and in others it is less. In the case of the lines at 6301·718 and 6302·709, which were used by Dunèr and Halm in their measures of the solar rotation, the difference exceeds 0·01A. Unfortunately these lines are amongst those which are displaced near the negative pole in the arc, and we cannot state precisely what their displacement is at the centre of the disc. However, for the purpose of this investigation, we have used these lines, and the line at 6280·833, as they are most conveniently situated with regard to the telluric oxygen lines of the *a* group, which form standards of reference from which the change of wave-length in the iron lines may be readily determined in spectra extending across the sun's disc. In addition to these lines in the red, it seemed desirable also to measure some lines in the ultra-violet, which probably represent a much higher level in the solar atmosphere, and for which the limb — centre shift is much smaller. As there are no telluric lines in this region, it was necessary to impress upon the plates emission lines from an arc spectrum to form standards of reference.

The method is to project a small solar image on the slit of the spectrograph, centring it precisely so that the wide spectrum obtained represents a diameter of the sun. An exposure is then made, sufficient to give a strong image of the spectrum of the more feeble light from the limbs; and in order to reduce and graduate the exposure for the central parts of the image a small strip of metal is held in front of the slit and moved up and down by hand during the exposure. With this simple device only a small amount of practice was needed to obtain sufficiently uniform density in the photograph.

In regions of the spectrum where there are suitable telluric lines, this procedure is all that is necessary to obtain photographs which will yield the required data. It is only necessary to measure the intervals separating the selected solar line from one or more telluric lines at the centre and at a number of points equidistant from the centre of the wide spectrum. The solar line will in general be inclined to the telluric lines by an amount depending on the latitude of the points of intersection of the slit with the sun's limb, this inclination being of course due to the Doppler shift of the solar rotation ; but in addition the measures will show that the line curves slightly towards the red at each end, and it is the nature of this curvature that is the subject of this investigation. A curvature in the same sense due to the action of the grating, being identical for both solar and telluric lines, does not affect the results.

In the more refrangible parts of the spectrum, where there are no telluric lines, we have found the arc spectrum of iron to be the most suitable substitute, because the iron spectrum has been more studied than any other, and it is very necessary to guard against errors due to the displacements of unsymmetrical arc lines near to the poles, which one of us has ascribed to a density effect. In the long arc necessary to impress the plate right across the wide solar spectrum, the wave-length of certain lines will change considerably as one pole or other is approached ; but by selecting symmetrical lines, it seems safe to assume that the wave-length will remain constant at all points, especially as the further precaution was taken of moving the arc continually up and down along the slit during the exposure, and reversing the poles so that half the exposure was made with the negative pole near the upper end of the slit, and half near the lower end. A difficulty in the use of the iron arc to determine the shifts of the solar iron lines is that the emission lines fall upon and obliterate the solar lines that it is desired to measure. This was overcome by the simple process of displacing the emission lines through a few angstroms by rotating the grating through an angle of one or two minutes of arc between the exposures on sun and arc. There is no danger in this procedure of changing the inclination of the arc lines.

Apparatus.—The large spectrograph described in Kodaikanal Observatory Bulletin No. XXXVI was used in this research, the only modification needed being the provision of an adjusting and guiding arrangement in front of the slit to ensure perfect bisection of the sun's image. A 3-inch lens of 5-feet focus was mounted in the beam of light from the siderostat, and the small solar image (14 mm. diameter) was projected on the slit by a reflecting prism. Immediately covering the slit-plate there was mounted a thin plate of brass with fine circular concentric lines engraved on it of diameters approximating to those of the greatest and smallest diameters of the sun's image. A slot about 1 mm. wide and 16 mm. long was cut in the plate along the vertical diameter of the circles to admit light to the slit, and the plate was then carefully adjusted by screws, so that the centre of the slot was coincident with the slit. To adjust the image concentrically with the circles, a telescope provided with a collimating lens is mounted so as to view the engraved plate, greatly magnified by the eye-piece. With the aid of the electric controls of the siderostat, the image viewed with the telescope may be kept as accurately concentric during an exposure as the definition of the sun's limb will permit.

Measurement of the spectra.—As high resolving power and linear dispersion are necessary in dealing with wave-length differences of less than 0·01A, the third and fourth orders of spectra given by the new Anderson grating were used, and these naturally involved rather long exposures both on sun and arc. Sixteen minutes were required to get dense images of the solar limbs in the third order red region, and almost as much in the fourth order violet at λ 4380, where the dispersion is 2·4 mm. to the angstrom ; but in the ultra-violet at λ 3928 good images of both sun and arc were obtained with six minutes' exposure. In the third order red the linear dispersion is 2·1 mm. to the angstrom, and in the fourth order violet at λ 3928 it is also slightly over 2 mm. to the angstrom. The resolving power may be judged from the definition of the very homogeneous oxygen lines in the a group: the first line of this group, 6276·815 of Rowland, is barely resolved into two lines with separation 0·030A ; and the line at 6278·303 is a clearly separated double with components at 6278·276 and 6278·330. Apparently not much would be gained by further increasing the resolving power, since the iron lines suitable for measurement in this region vary from 0·08 to 0·11A in width, and it is this, and the diffusive character of their edges, which sets a limit to the accuracy of the measures.

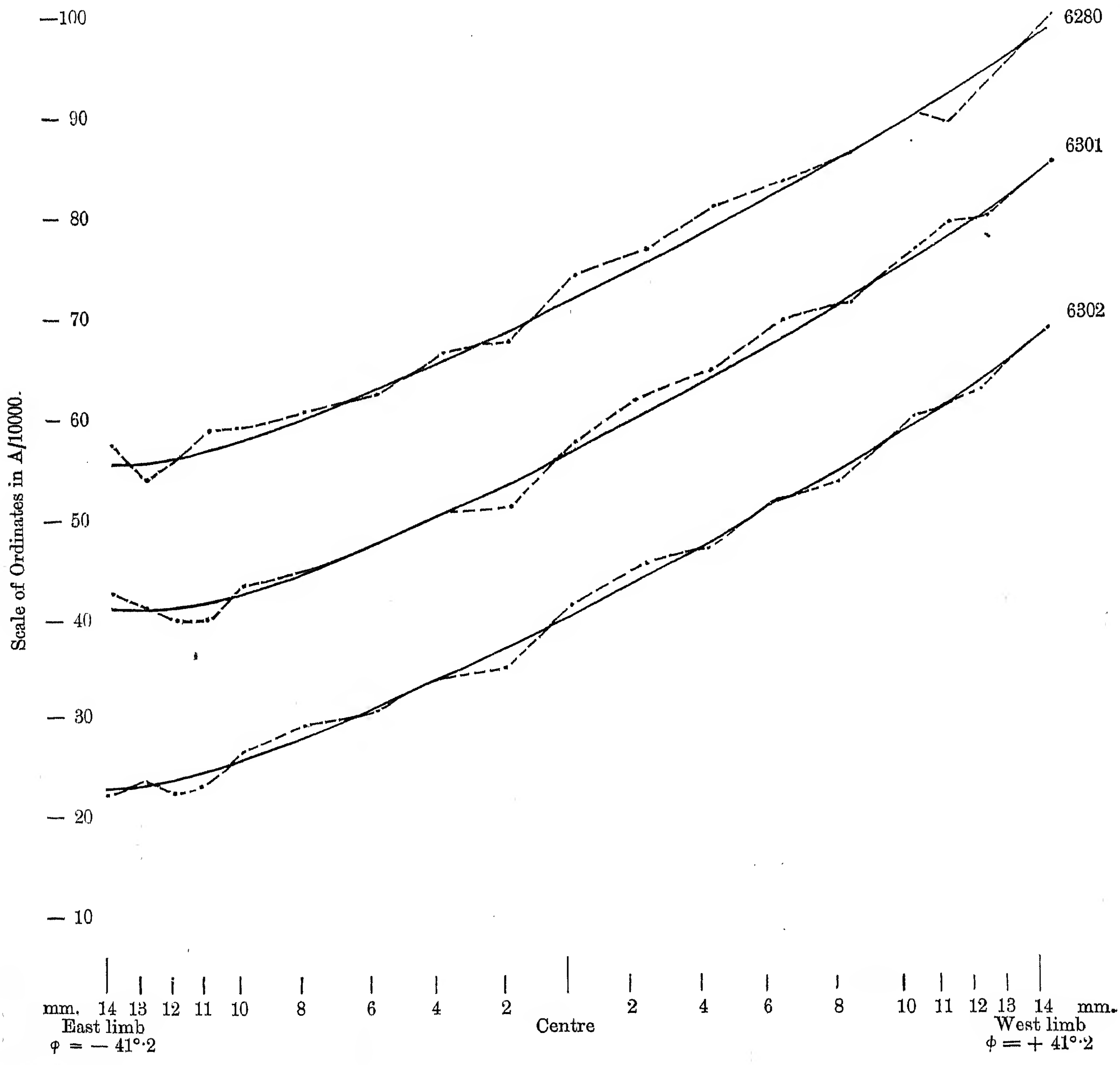
The three lines measured in this part of the spectrum are all within the group of telluric oxygen lines, and are well adapted for the positive on negative method of measurement described in Kodaikanal Observatory Bulletin No. XXXII. They have a large limb — centre shift, but probably a very small or even negative

centre — arc shift. For the line 6280 it is a small positive shift but for the other two at 6301 and 6302 it is negative in all the arc and sun comparisons we have made, even when the centre of a long arc is used, but the unsymmetrical nature of the lines makes it difficult to determine how far this may be due to a displacement in the arc.

At the other end of the spectrum we have taken, amongst others, the symmetrical Fe lines 3928·075 and 3930·450, which have a small limb — centre shift, but a large centre — arc shift. The narrow chromium line at 3928 783 was also measured, and the narrow spark lines of Fe and Ti at 4385·548 and 4387·007, which according to Adams have a relatively large limb shift for this part of the spectrum. For all but the red lines, the positive on negative method of measuring was found difficult to apply, and recourse was had to the ordinary method of bisection with a spider-thread, taking the mean results from the original negative and from a positive copy.

For the measurement of these spectra, which have a width of about 28mm., a special cross slide provided with a millimetre scale was constructed for the micrometer, and for the positive on negative measures a cross slide had to be provided for both positive and negative images. In either method of measuring, the plate or

FIG. 1.—DISPLACEMENTS OF FE LINES ACROSS SUN'S DISC.



plates have to be moved across the field of view in the direction of the spectrum lines by successive measured intervals from one edge of the spectrum to the other, the field of view being limited to a narrow strip, either by a mask placed over the plate, or in the positive on negative measures by a mask placed in the eye-piece. The movement is made by a screw bearing on the edge of the sliding plate-carrier.

As the change of wave-length in passing from the centre of the spectrum to the edge is most rapid near the edge, the 14 mm. representing the solar radius is divided into 2 mm. intervals as far as 10 mm. from the centre, and thence into 1mm. intervals, to 13 mm. The final measure is made at a point 0·25 mm. within the limb. In this way, including the measure of the central strip, a series of nineteen determinations of the relative positions of the solar and telluric, or solar and arc lines, is obtained, representing points on the sun's disc the heliographic co-ordinates of which can be determined from the known position-angle of the slit at the time the plate was exposed. The measured intervals between solar and reference line, or their differences, are then plotted, and a smooth curve drawn, from which a small correction to the central interval is obtained, and the other intervals are freed from accidental errors of measurement and possible real irregularities of wave-length. This smoothing process might however have been omitted altogether without seriously affecting the mean results obtained from several plates: its main purpose is to get a corrected value of the wave-length at the centre of the disc, and hence more correct values of the shifts between limb and centre. There is some evidence of real, though unsystematic, irregularities of wave-length confirmed by the different lines on a plate, and amounting at the most to ± 0·002A. We give as an example of this the curves in fig. 1, representing the measures of the lines 6280, 6301 and 6302, on the date November 14, 1914. At 2 mm. east of the centre the wave-length of all three lines is in defect, whilst at the centre and at 2 mm. west it is in excess of the values derived from the smooth curve. As different reference lines were used for each of the three iron lines, this is good evidence of real variation, especially as the lines are best defined near the centre, and the variation is about four times greater than the probable error of measurement.

However disconcerting such fortuitous irregularities may be, they are of interest in showing the slight instability of the lines of the solar spectrum, and the need for great caution in interpreting the results from a single plate in all researches connected with line displacements in solar spectra, and especially in solar rotation work.

In the reduction of the measures it is generally necessary to compute the component in the line of sight of the rotation velocity for each point measured. At times when the solar equator passes through, or very near, the centre of the disc, this is not essential, since the plus and minus velocities on the east and west halves of the diameter then cancel one another: when, however, the sun's axis is inclined to the direction of the earth there are appreciable differences, and although these are small, it was considered worth while to compute by an appropriate formula the corrections to be applied to the observed displacements in order to remove the effect of the solar rotation entirely. A comparison of the observed and computed velocities could then be used as a check on the general reliability of the measures.

Adopting Adams' formula for the sidereal solar rotation as correctly representing the change of velocity with latitude, the complete formula used for finding the component in the line of sight of the synodic rotation velocity at any position on the sun's disc is :—

$$(1{\cdot}507 \cos \phi + 0{\cdot}456 \cos^3 \phi - C) \sin \lambda . \cos D.$$

The latitude, ϕ, is determined graphically by plotting the positions of the measured points on the appropriate solar chart, of which the Observatory possesses an excellent set, carefully constructed by the Rev. Father Beaurepaire. C is the correction found from Dunèr's solar tables for converting sidereal into synodical velocity. This is an unnecessary refinement, but its inclusion enables us to compare readily the observed with the computed line shifts. Sine λ (the heliographic longitude) is obtained by the formula :—

$$\text{sine}\,\lambda = \text{central distance} \times \text{sine angle between sun's axis and slit} \times \text{secant}\,\phi$$

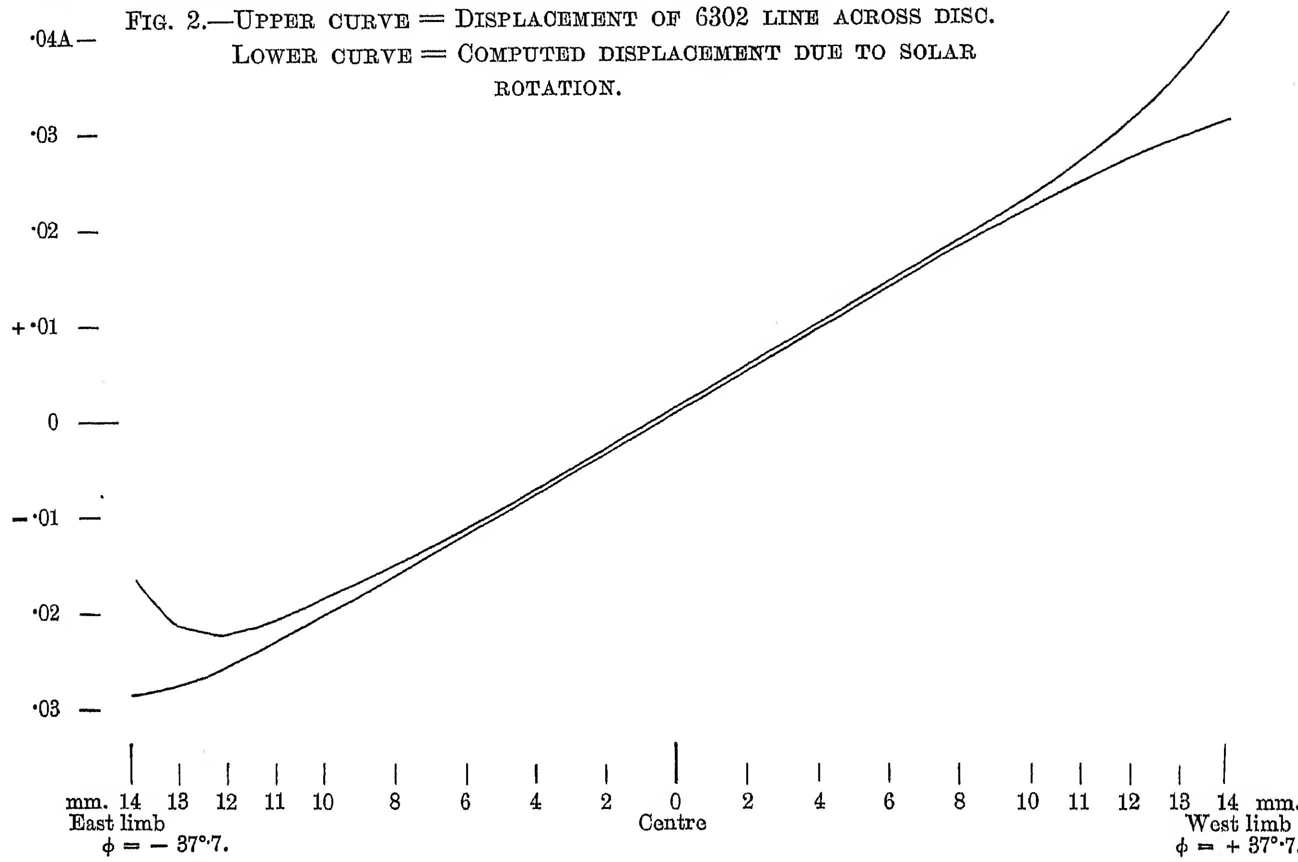
D is the inclination of the sun's axis to the line of sight.

In our experience during the years of sunspot minimum, the constants in Adams' formula generally give too large a value for the solar rotation ; but since we are only concerned here in finding the difference of shift between points east and west of the centre, any errors in these constants will have no appreciable effect.

In fig. 2 we give a smoothed curve representing the measures of the line 6302, on the date November 24, 1914 when the latitude of intersection of the slit and limbs was 37°·7. The curve of computed displacements

due to the solar rotation is also given, slightly displaced with regard to the other curve, to show the parallelism of the two near the centre, and their departure as the limb shift begins to be manifest. In this particular plate the results of the rotation shift are in remarkably close agreement with the computed shifts from Adams'

FIG. 2.—UPPER CURVE = DISPLACEMENT OF 6302 LINE ACROSS DISC.
LOWER CURVE = COMPUTED DISPLACEMENT DUE TO SOLAR ROTATION.



formula. In comparing these, we take the mean of the shifts at corresponding points east and west of the centre, both for the observed and computed shifts, in this way eliminating the limb shift. In table I we give the results for the three lines measured on the above date. In the mean values for the three lines the largest residual is only three in the fourth decimal, and the mean percentage difference about ¼ per cent under the computed values.

TABLE I.

Shifts of iron lines between centre and limb, due to component of solar rotation. In A/10000. (ϕ at limb = 37°·7.)

Central distance.	6280	6301	6302	Mean.	Computed.	O — C	Percentage difference.
MM							
2	46	45	45	45	45	0	0
4	90	87	87	88	88	0	0
6	134	130	130	131	132	−1	−0·76
8	174	168	170	171	172	−1	−0·58
10	211	208	211	210	211	−1	−0·47
11	233	229	231	231	234	−3	−1·28
12	254	249	252	252	251	+1	+0·40
13	269	269	268	269	268	+1	+0·37
13·8	278	282	270	277	276	+1	+0·36
Mean percentage difference ...							−0·22

About the same order of accuracy is shown by the positive on negative measures of the three plates obtained on November 14, 1914, but in these the mean rotation values are about 2½ per cent smaller than those derived from Adams' formula.

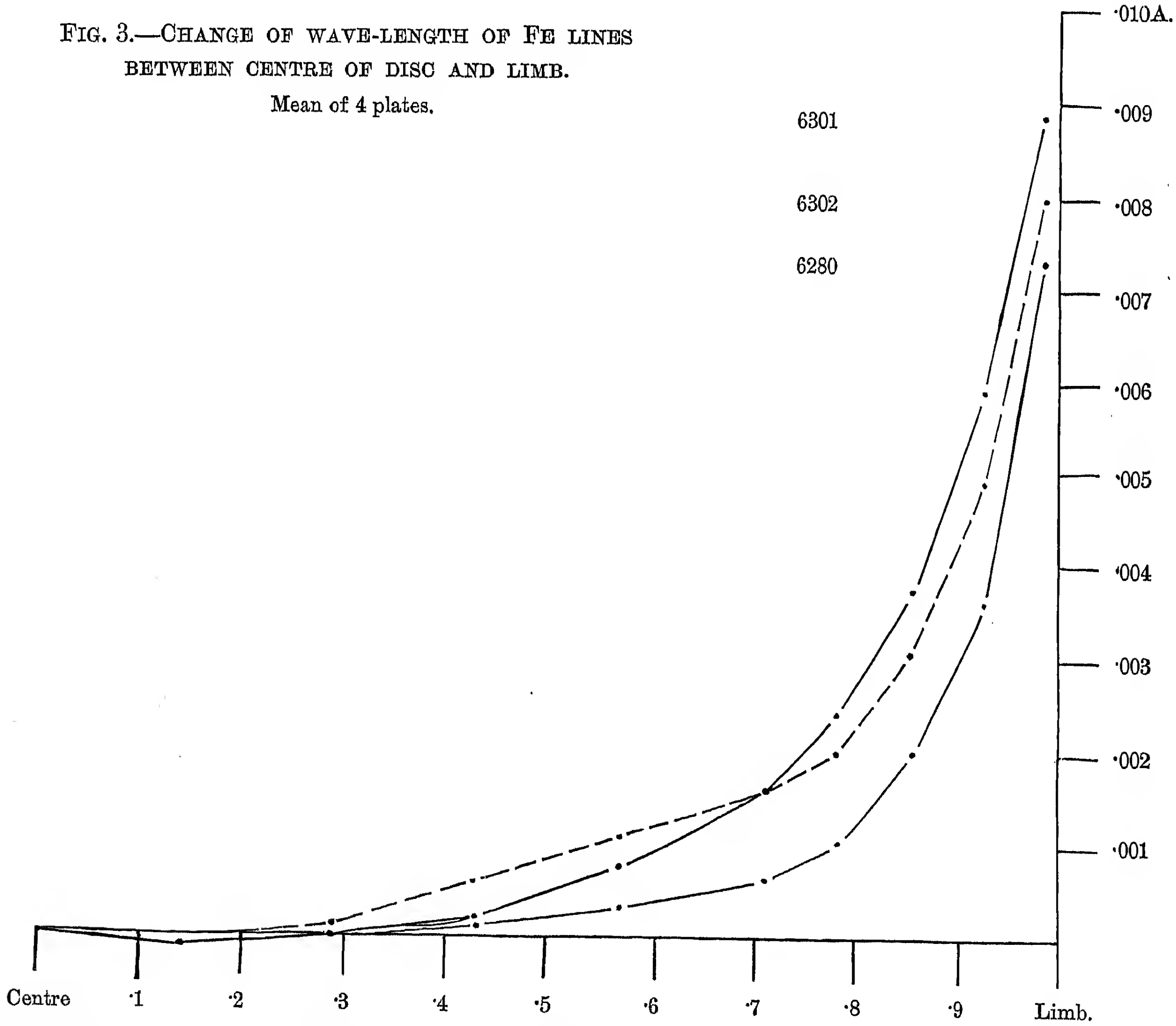
These results serve to indicate the accuracy attained in the measurement of these rather wide lines by the positive on negative method. Measures have also been made of the same lines in other plates by the ordinary method, and by another measurer, and whilst the general form of the curve representing the shift across the disc is the same, there is a less satisfactory accordance in the rotation shifts. The same remark applies also to the ultra-violet lines measured in the ordinary way, the chromium line at 3928·783 and the Fe and Ti lines at 4385·548 and 4387·007 giving the best results, on account of their narrowness and well-defined character.

The stronger ultra-violet lines measured are those at 3928·075 and 3930·450. These give very small limb shifts, and in some plates it appears to be a negative shift : the displacement is towards violet instead of towards red. As these lines are rather wide, and the measures are difficult, we have some doubt as to the reality of the negative shifts. It suggests a variability of the limb shift, of which we have indications also in some of the measures of the red lines.

Results of the measures.—Leaving the question of the negative shifts for further investigation, we now proceed to give the results of the measures, after elimination of the rotation shift, and taking the mean of the east and west displacements. The diagram fig. 3 exhibits the mean change of wave-length between the centre of the disc and the limb of the Fe lines 6280, 6301, and 6302. These are derived from four plates

FIG. 3.—CHANGE OF WAVE-LENGTH OF FE LINES BETWEEN CENTRE OF DISC AND LIMB.

Mean of 4 plates.



measured by the positive on negative method. The abscissæ are here given in tenths of the solar radius, and the ordinates in angstroms. The latitudes of the points of intersection of slit and limbs varied between 26°·4 and 41°·2, the mean being 35°·6. The plates were secured on dates November 14 and 24, 1914, under practically perfect atmospheric conditions.

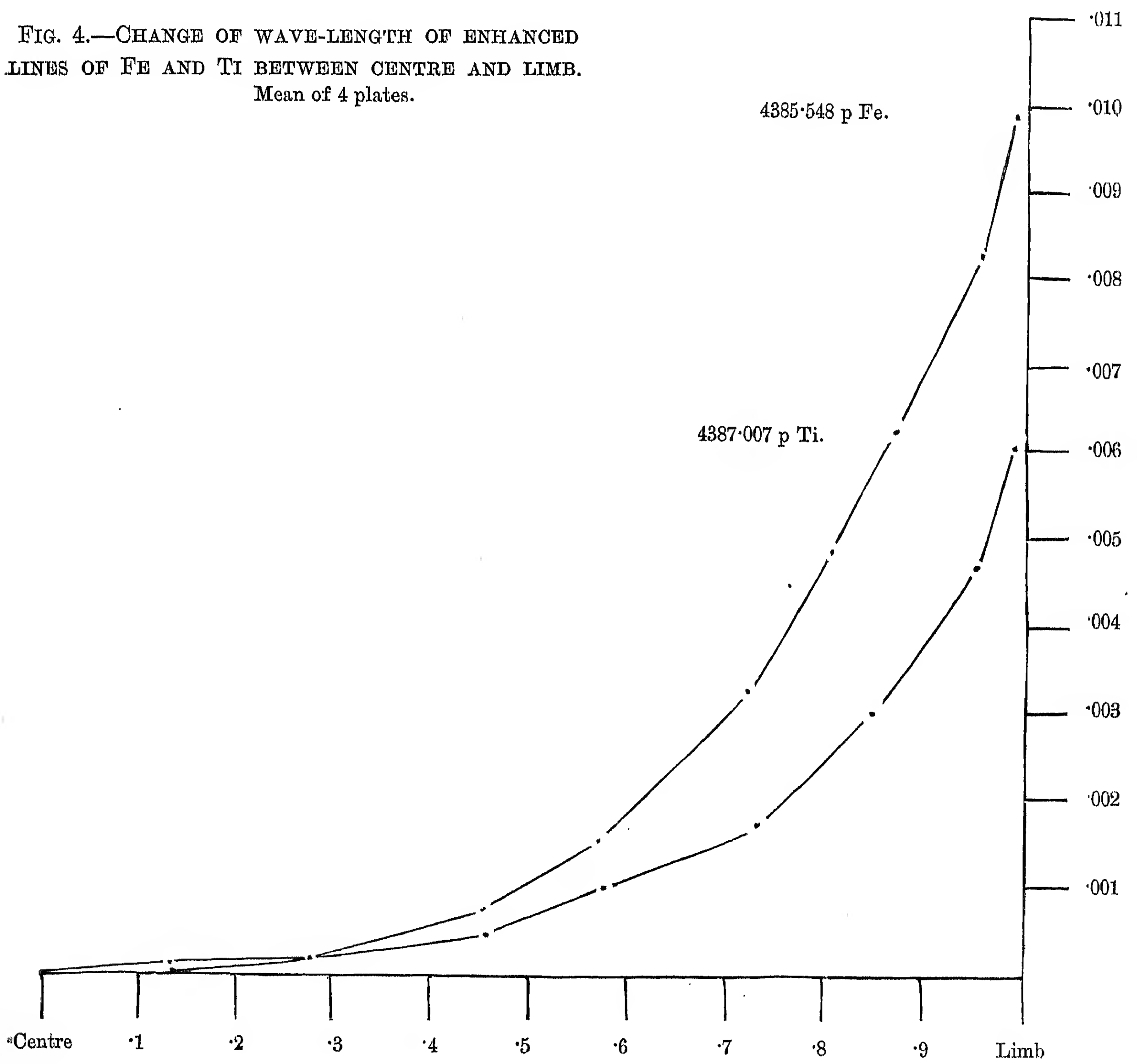
The outstanding feature of the curves is the small distance from the centre at which the limb shift begins to manifest itself. This begins at approximately 0·3 of the radius from the centre for all three lines, but

the curve for the 6280 line falls below the other two, the increase of wave-length being at first less rapid than for the line 6301. There is also a slight indication of a decrease of wave-length for the line 6301 at the point measured nearest to the centre. This decrease does not exceed 0·0002A, and must be considered doubtful. Three of the four plates measured give minus values, and one a plus value.

Two other plates taken on March 18 and 19, 1915, at latitudes 82°·3 and 86°·9 (the slit being almost coincident with the sun's axis) were measured by the ordinary method. Taking the mean results of a positive and a negative image, these show rather larger limb shifts for the lines 6301 and 6302, but a smaller shift for the line 6280. The rates of increase between centre and limb are however very similar to those given in the curves. It cannot be said that latitude has any appreciable influence on the limb shifts, which appear to be the same at all points on the circumference of the sun. But, as already mentioned, there is some evidence of variability of the limb shift on plates taken on different dates, which needs further investigation. For instance, a plate taken on December 25, 1914, at latitude 69°·1, yields remarkably small limb shifts for all three lines, the values being about one half of those usually obtained. It may be added that all of the plates were taken under conditions of exceptional purity of sky, although the definition of the sun's image may have varied considerably.

Fig. 4 shows similar curves for the lines 4385·548 and 4387·007. These lines were selected because they have relatively large limb shifts for this part of the spectrum, and they fall near to the strong Fe line

FIG. 4.—CHANGE OF WAVE-LENGTH OF ENHANCED LINES OF FE AND TI BETWEEN CENTRE AND LIMB. Mean of 4 plates.



4383·720, a symmetrical line which is readily reversed in the arc, the absorption line forming an excellent line of reference. They are due to enhanced Fe and enhanced Ti respectively. Four plates were exposed on October 9, November 19 and 23, 1914, the latitudes of intersection of slit and limb being 27°·3, 55°·6, 50°·4 and 51°·7.

Fig. 5 shows the ultra-violet lines measured. The lower curve is the mean result obtained for the two strong iron lines 3928·075 and 3930·450. These lines, as already stated, have a very small limb shift and

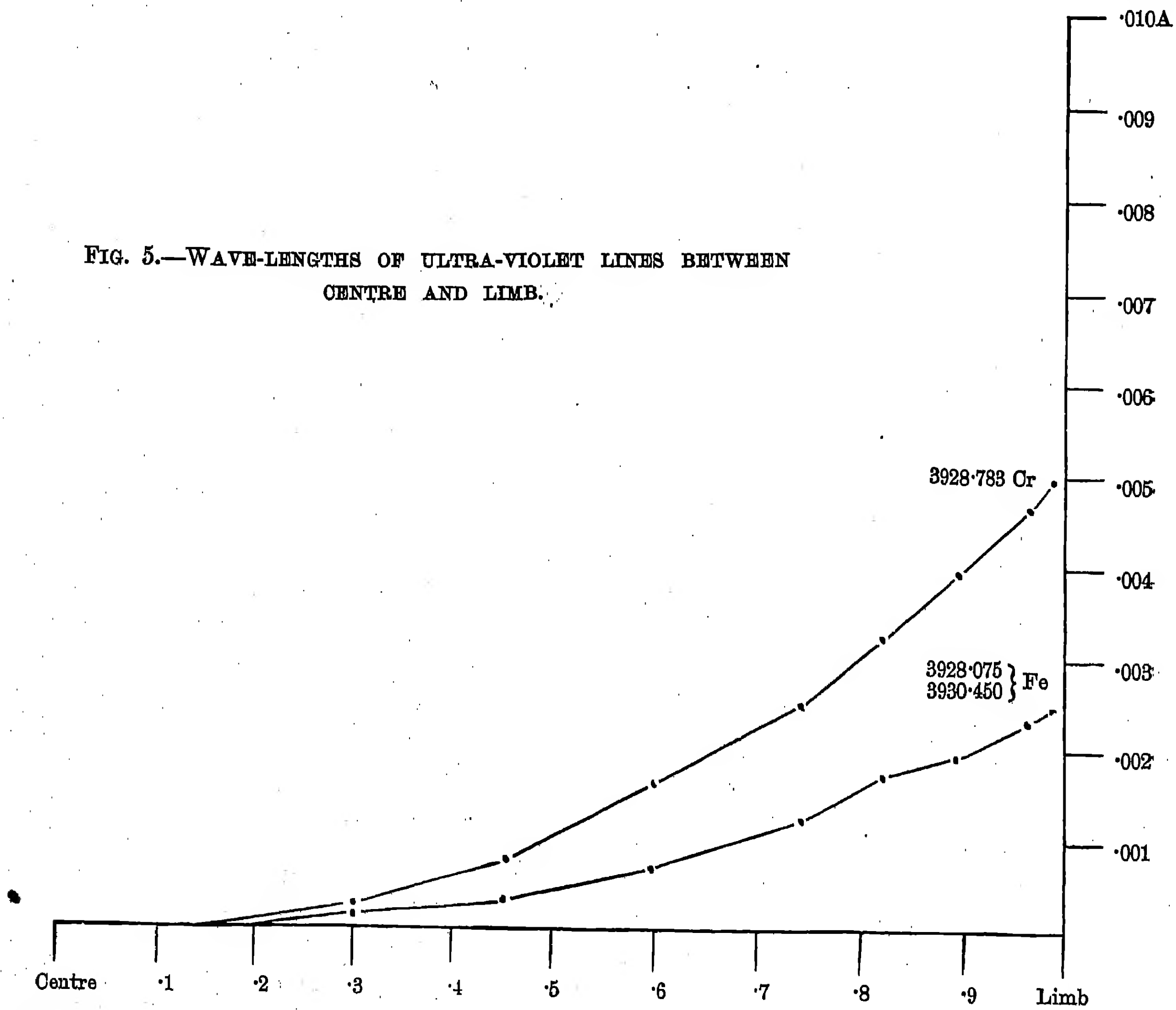


FIG. 5.—WAVE-LENGTHS OF ULTRA-VIOLET LINES BETWEEN CENTRE AND LIMB.

a large centre — arc shift. As there is no appreciable difference between them, the mean of the two is given, from two plates. The upper curve in this diagram is the narrow chromium line 3928·783, the mean of four plates. The data for this diagram are derived from plates taken on December 25, 27 and 28, 1914, and January 8, 1915. The latitudes range from 40°·4 to 81°·2.

Comparing these ultra-violet lines with those at the red end of the spectrum, we find the increase of wave-length begins at about the same distance from the centre in both; but the ultra-violet lines, and especially the strong iron lines, show a very much smaller rate of increase near the limb than the red lines. The enhanced lines in fig. 4 give essentially the same type of curve as the red iron lines.

Discussion of results.—In Kodaikanal Observatory Bulletin No. XLVI the question was raised as to whether the general movement of recession indicated by the displacement of the iron lines towards red at the centre of the sun's disc was the result of a circulation of the solar gases in a direction radial to the sun, or was part of a general movement of recession from the earth. The present series of measures appears to show that the displacements at the centre are not due to a radial circulation on the sun, but are probably part of a general displacement increasing from the centre towards the limb. If the descending movement at the centre of

the disc were due to a circulation radial to the sun, the component of motion in the direction of the earth would diminish from the centre towards the limb in proportion to the cosine of the angular distance from the centre, and this would be apparent in an initial decrease of wave-length, most marked for those lines having a large centre—are shift. This decrease would continue until counteracted by the increasing limb shift, producing a displacement curve across the disc very different in form from that actually found. So far as we have gone, the line 6301 is the only one which shows any tendency to a decrease of wave-length, but this line has a very small, or possibly a negative, shift at the centre of the disc, while the strong lines in the ultra-violet which have a mean centre — arc shift of 0·016A exhibit no diminution of wave-length, but a continuous increase from a point not very far from the centre.

In Kodaikanal Observatory Bulletin No. XXXIX it was shown that the relative shifts between the limb and centre cannot be explained by a difference of pressure in the effective regions of absorption at the limb and at the centre of the disc, and the displacement curves now found afford additional evidence in the same sense, as the following considerations will make clear.

According to Halm's hypothesis, at the limb the path of the light through the lower layers is increased in greater ratio than that through the upper layers. It is easily seen, however, that owing to the slight depth of the reversing layer this effect can only be appreciable very near to the limb. It is sufficient to calculate the ratio between the thickness of a layer at the bottom of the reversing stratum and one at the top, since for these extreme layers there is the maximum possible difference. In fig. 6 let O be the centre of the sun, and P the centre of the disc seen from the earth. A ray of light starts towards the earth from A on the photosphere at

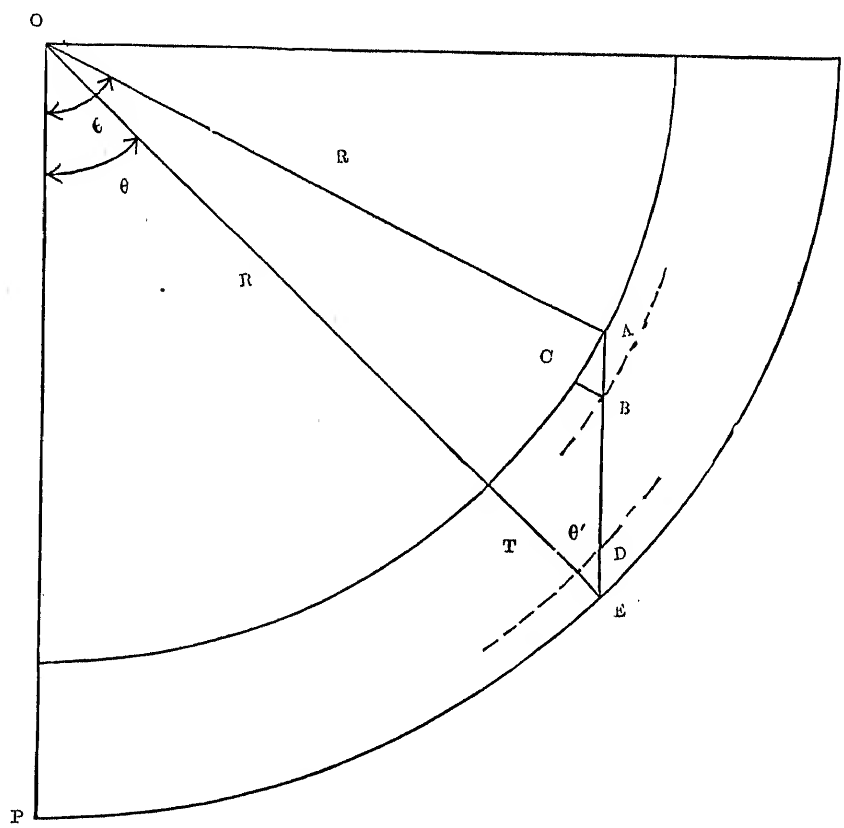


FIG. 6.

angular distance θ from the centre of the disc, and emerges from the reversing layer at E, at distance θ' from the centre of the disc. Then θ' is given by the relation

$$\sin \theta' = \text{R.} \sin \theta / \text{R} + \text{T} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

where R equals the radius of the sun, and T equals the total thickness of the reversing layer. Now the length of path AB of the ray through a thin layer of thickness BC = d at the base of the reversing layer is $d/\cos \theta$, and similarly the length of path DE through an equally thick layer at the summit is $d/\cos \theta'$. The relative increase in the lowest layer is therefore

$$\cos \theta' / \cos \theta$$

This ratio is given in the following table, obtained with the help of equation (1), assuming that the sun's radius equals 960″, and the total thickness of the reversing layer equals 2″.

TABLE II.

θ	$\cos\theta$	$\sin\theta$	$\sin\theta' = 960/962 \times \sin\theta$	θ'	$\cos\theta'$	$\frac{\cos\theta'}{\cos\theta}$
0°	1·0000	0·0000	0·0000	0° 0′	1·0000	1·000
45°	0·7071	0·7071	0·7067	44° 53′	0·7083	1·001
70°	0·3420	0·9397	0·9377	69° 40′	0·3474	1·016
75°	0·2588	0·9659	0·9640	74° 34′	0·2661	1·028
80°	0·1736	0·9848	0·9827	79° 20′	0·1828	1·053
82°	0·1392	0·9903	0·9882	81° 12′	0·1530	1·099
85°	0·0872	0·9962	0·9942	83° 47′	0·1083	1·242
88°	0·0349	0·9994	0·9973	85° 48′	0·0732	2·097
90°	0·0000	1·0000	0·9979	86° 18′	0·0645	∞

Whatever assumptions we may make as to the difference of pressure in the upper and lower layers, and also as to the effect of the difference of path on the pressure displacement of a line, it is evident from this table that no difference of path is appreciable except between 85° and 90° from the centre, and therefore no change of wave-length can occur except quite close to the limb. Thus, at about 85°, or 0·996 of the radius from the centre, we might expect a line to begin to be widened on the red side, the violet edge remaining in its normal position owing to the absorption at the highest level. This widening would be of a diffuse character, since the rays of light would traverse successive layers of decreasing pressure and temperature. The effect of a higher temperature in the lowest strata would indeed tend to neutralize the increased absorption due to a longer path, and it is by no means clear that any displacement whatever would be observed. However this may be, as all the displacement curves agree in showing that the shift is continued far within the limb, it cannot be due to the effect of pressure differences. The pressure theory of both limb and centre shifts is also difficult to reconcile with recent views as to the effective depths in the reversing layer where absorption occurs. For we now believe that the fainter lines originate at greater depths than the stronger lines, consequently they should give larger shifts at the centre of disc because of the greater pressure, and smaller limb — centre shifts because of the smaller difference of path for radial and tangential rays. This is just the opposite of what is actually found ; on the average the fainter lines have smaller centre — arc shifts and larger limb — centre shifts than the stronger lines.

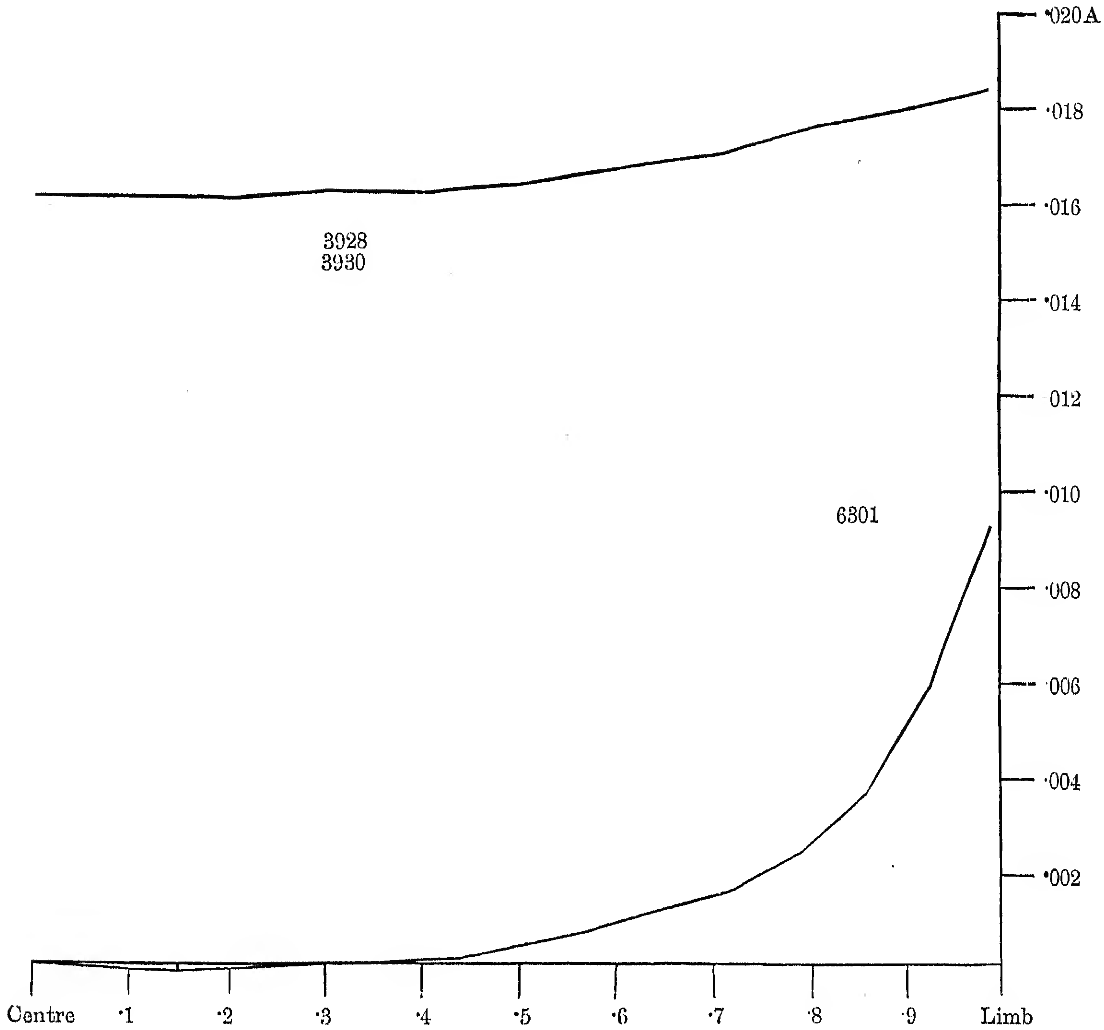
Owing to the remarkable inverse relation between the limb shift and the centre shift which has been shown to exist (Kodaikanal Observatory Bulletin No. XXXIX), we seem justified in assuming tentatively that both are due to a single cause, and one in which pressure plays no part. But the centre shifts have been interpreted as due to descending movement, which is greatest in the higher levels, and decreases, possibly to zero, in the lower levels of the reversing layer [1] ; and this interpretation has been endorsed by Dr. St. John.[2] If the limb shift is also a Doppler effect we may add the two shifts, and represent the change of wave-length between centre and limb as in the diagram fig. 7, in which the upper curve represents the ultra-violet lines 3928·075 and 3930·450, and the lower curve the red line 6301·718, which we will assume has a zero centre—arc shift.

If we accept St. John's conclusions as to the different levels represented by lines in different spectral regions, the ultra-violet lines represent a high level, and therefore show the large descending velocity of which the ordinate 0·016A is the equivalent. The red line, on the other hand, represents a very low level, and is produced in a region where this downward movement is arrested. At the limb, however, there is much less difference in the displacements, the wave-length of the red line being increased by 0·010A, and the wave-length

[1] Kodaikanal Observatory Bulletin Nos. XXXVI and XXXIX. [2] Mt. Wilson Annual Report, p. 256, 1914.

of the violet lines by 0·002 only. The velocities at the limb will then be for the red line 0·5 km/sec, and for the violet lines 1·4 km/sec.

FIG. 7.



We thus see that at the limb a great depth of the reversing layer is affected by the movement, while at the centre of the disc only the upper layers are in motion. If we could conceive of the Earth exerting a repulsion on the solar gases, this behaviour of the high-level and low-level lines becomes intelligible ; for at the centre of the disc the resistance of the denser layers and of the photosphere itself would arrest any downward movement, while at the limb the entire stratum would be more or less free to move tangentially to the solar surface.

The velocity interpretation of the limb shifts inevitably leads to an Earth effect, even if we assume a combination of radial and surface currents on the sun to account for the observed displacement curves. Formulæ combining a radial and a surface current can be constructed to fit the displacement curves satisfactorily, but the surface current must be towards or away from the centre of the disc, a point on the sun which has no significance except in relation to Earth. Also as the radial currents involve an ascending motion, whilst we find a descending movement, it seems futile to discuss these formulæ.

To escape from the hypothesis of an Earth effect, we must assume that the solar line shifts depend upon the direction which the rays of light take in traversing the reversing layer, the shift being least for rays passing normally through it, and most for the tangential rays. The effects of anomalous dispersion will no doubt appeal to many as giving a probable explanation of the facts, and doubtless the anomalous dispersion theory would lend itself admirably to this problem as to so many others.

We consider nevertheless that the Doppler hypothesis should not be lightly discarded until indisputable evidence is forthcoming that anomalous dispersion is really an effective agent in displacing solar lines. The recent work of Albrecht in regard to this appears to us to be entirely discounted by our measures of close double lines in sun and arc,[1] and by the subsequent disclosure of very large overestimates in Rowland's measures of the separations of many solar double lines. The actual close agreement in the separations of arc and solar double lines seems indeed to rule out anomalous dispersion as an effective agent in displacing solar lines.

It remains to mention a crucial experiment which would decide the question whether the displacements are due to motion radial to the Earth, and affect only that side of the sun directed toward the Earth, for by the aid of the planet Venus we can compare the generalized spectrum of a hemisphere of the sun turned 90° or more from the Earth with the hemisphere facing the Earth. If the displacement of the solar lines affects only the hemisphere facing the Earth, there will be a difference of wave-length between the lines of the planet's spectrum, when corrected for her motions in the direction of Earth and sun, and those of ordinary sunlight.

It is probable that with modern instruments the line-of-sight velocity of Venus could be readily determined with a probable error as small as $\pm$ 0·2 km/sec, while the difference of wave-length expected corresponds to from 0·6 to 1 km/sec, according to the lines chosen.

If there is no such difference of wave-length between the light from the two sides of the sun, then it will be necessary to find some explanation of the line shifts other than motion in the line-of-sight.

SUMMARY.—(1) The first part of this paper describes the method of obtaining spectra representing a diameter of the sun, and the use of the telluric lines at the red end of the spectrum, and the reversals of the superposed arc lines of iron at the violet end, as reference lines for determining the displacements of the solar lines across the disc between centre and limb.

(2) The methods of measurement and reduction are described, and the accuracy of the positive on negative method of measuring is illustrated by comparing the observed with the calculated shifts due to the components in the line-of-sight of the solar rotation movement.

(3) Small irregularities disturbing the smoothness of the curve which represents the change of wave-length between centre and limb are indicated.

(4) Diagrams are given showing the change of wave-length between centre and limb of the red lines 6280·833, 6301·718 and 6302·709, of the violet lines 4385·548 and 4387·007, and of the ultra-violet lines 3928·075, 3928·783 and 3930·450.

(5) The form of these curves indicates that the redward shift, or downward movement, at the centre of the disc is not due to a radial circulation of the solar gases, but is probably part of the general displacement increasing towards the limb.

(6) It is shown that a difference of pressure between the effective region of absorption at the limb and at the centre of the disc will not account for the displacement curves, since the limb shift continues for a long distance within the limb, while a pressure effect could only be appreciable from ·996 radii from the centre to the limb.

(7) It is suggested tentatively that both limb shift and centre shift are due to a single cause, a general movement directed away from the Earth, all over the disc. This movement affects only the higher parts of the reversing layer at the centre of the disc, because of the resistance offered to a downward movement by the lower layers or the photosphere : at the limb the movement affects the lower strata also, because there is little resistance to a movement to the solar surface.

(8) It is suggested that observation of the wave-length of the lines in the spectrum of Venus would decide the question whether the shifts are due to a recession from the Earth.

THE OBSERVATORY, KODAIKANAL,
4th March 1916.

J. EVERSHED.
T. ROYDS.

[1] "The Observatory," January, 1916.

[*Price*, 8 *annas*.]

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Kodaikanal Observatory.

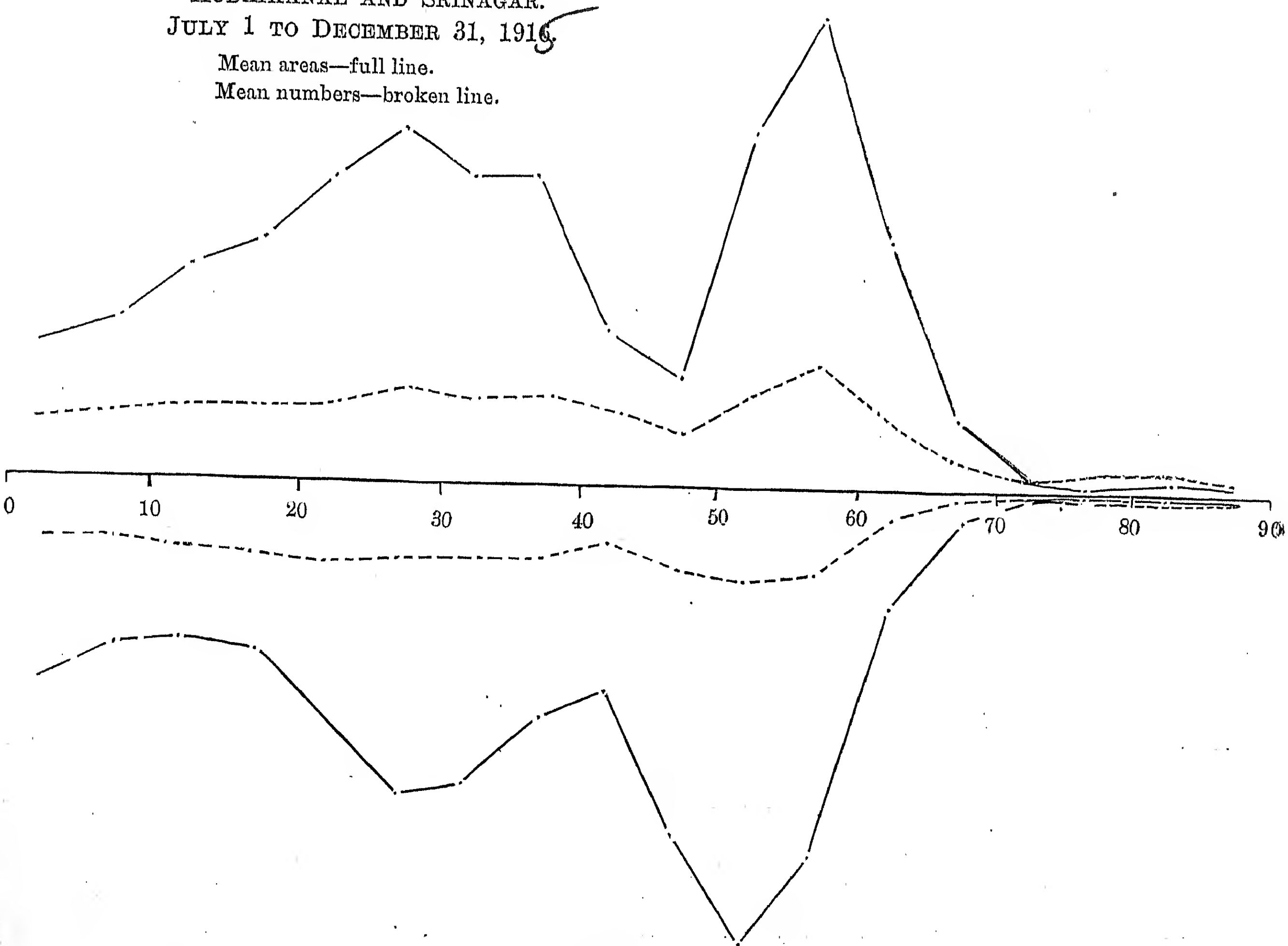
BULLETIN No. L.

SUMMARY OF PROMINENCE OBSERVATIONS FOR THE SECOND HALF OF THE YEAR 1915.

In this bulletin the prominence observations made at Srinagar since August 8 by the Kashmir expedition under Mr. J. Evershed, the Director, have been used to supplement those made at Kodaikanal. At Kodaikanal the visual observations were practically confined to displacements of the hydrogen lines and to metallic prominences, as the position angles, heights and areas can now be much more satisfactorily determined from the photographs. For those days when the Kodaikanal photographs of prominences were incomplete, imperfect or wanting, the visual observations made at Srinagar were substituted. With this aid of the Srinagar observations there were no prominence observations on only six days (all in December) between August 8 and December 31, and incomplete or imperfect observations on only three days. In the whole six months observations were made on 162 days, counted as 157 effective days.

The distribution of prominences observed and photographed during the half-year ending December 31, 1915, is represented in the accompanying diagram. The full line gives the mean daily areas and the broken line the mean daily numbers for each zone of 5° of latitude. The ordinates represent tenths of a square minute of arc for the full line and numbers for the broken line.

FIG. 1.—MEAN AREAS AND MEAN NUMBERS OF PROMINENCES,
KODAIKANAL AND SRINAGAR.
JULY 1 TO DECEMBER 31, 1916.
Mean areas—full line.
Mean numbers—broken line.



The distribution, which is practically unaffected by the inclusion of Srinagar observations, is very similar to that in the first half of the year, but there is a large reduction in the number of polar prominences.

The mean daily areas and daily numbers (corrected for partial observations) are given in the table below, where the data for Kodaikanal observations alone are also given separately for the sake of uniformity with previous bulletins. It is seen that the inclusion of Srinagar observations has slightly reduced both the daily areas and daily numbers ; this is probably due to the fact that only visual observations at Srinagar were used.

		Mean daily areas (square minutes).	Mean daily numbers.
Kodaikanal and Srinagar Observations (157 effective days).	North	2·46	7·89
	South	2·49	7·40
	Total ...	4·95	15·29
Kodaikanal Observations (122 effective days).	North	2·62	8·15
	South	2·67	7·69
	Total ...	5·29	15·84

Compared with the previous six months there is a large diminution in the mean numbers but only a slight one in the mean daily areas. The average area of a prominence has consequently increased.

The monthly, quarterly and half-yearly frequencies and the mean height and extent of the prominences observed at Kodaikanal are given below in the following table. The frequencies are derived from the number of effective days.

Abstract for the second half of 1915 (Kodaikanal).

Month.	Number of days of observations.		Number of prominences.	Mean daily frequency.	Mean height.	Mean extent.
	Total.	Effective.				
1915.					″	°
July	18	15	218	14·5	37·5	2·77
August	23	21	268	12·8	50·8	4·92
September	24	20	250	12·5	46·7	3·84
October	27	26	466	17·9	42·5	3·56
November	22	19	325	17·1	40·1	3·30
December	21	21	406	19·3	39·2	2·95
Third quarter ...	65	56	736	13·1	45·0	3·92
Fourth quarter ...	70	66	1,197	18·1	40·7	3·24
Second half-year ...	135	122	1,933	15·8	42·5	3·47

There is a large increase (40 per cent) over the previous half-year in the mean height which accounts for the increase in the average area of a prominence mentioned above.

Distribution east and west of the sun's axis.

In the observations at Kodaikanal and Srinagar combined, numbers show a slight preponderance at the western limb, and areas a slight preponderance at the eastern limb.

1915, July to December.	East.	West.	Percentage east.
Numbers observed	1,196	1,204	49·83
Total areas in square minutes	3,892	3,880	50·08

Metallic prominences.

The following metallic prominences were recorded in the half-year. Since the Srinagar observations were generally made at a later hour than those at Kodaikanal, the metallic prominences observed at the two stations, as well as the displacements in prominences, have generally little relation to each other and are therefore given in separate lists.

TABLE I-A.—LIST OF METALLIC PROMINENCES OBSERVED AT KODAIKANAL. JULY—DECEMBER, 1915.

Date.		Time I.S.T.		Base.	Latitude.		Limb.	Height.	Remarks.
					North.	South.			
1915.		H.	M.	°	°	°		"	
July	8	9	0	6	...	22	W	30	D_1, D_2, b_1, b_2, b_3, b_4.
	10	8	58	8	...	26	E	40	D_1, D_2, b_1, b_2, b_3, b_4.
August	10	8	33	5	...	16	W	125	D_1, D_2, b_1, b_2, b_3, b_4, 6677, C symmetrically widened.
	14	8	52	2	...	16	E	30	D_1, D_2, b_1, b_2, b_3, b_4, 7065, 6677.
	29	8	50	4	...	21	E	45	D_1, D_2, b_1, b_2, b_3, b_4.
September	14	8	32	17	...	31	W	50	D_1, D_2, b_1, b_2, b_3, b_4.
	23	9	18	2	19	...	W	45	D_1, D_2, b_1, b_2, b_3, b_4, 6677, 7065.
October	3	8	27	2	11	...	W	60	6677, D_1, D_2, b_1, b_2, b_3, b_4.
	20	8	46	9	...	25·5	E	...	D_1, D_2 slightly reversed.
November	9	8	52	...	...	14	E	50	D_1, D_2, b_1, b_2, b_3, b_4.
	25	8	56	2	...	21	W	25	D_1, D_2, b_1, b_2, b_3, b_4.
December	5	8	35	1	...	20·5	W	25	D_1, D_2, b_1, b_2, b_3, b_4 slightly reversed.
	6	8	55	10	25		W	55	D_1, D_2, b_1, b_2, b_3, b_4, 5316·8.
	7	8	40	6	...	28	E	50	D_1, D_2, b_1, b_2, b_3, b_4.
	10	8	46	1	...	23·5	W	40	D_1, D_2, b_1, b_2, b_3, b_4 strongly reversed (whole prominence seen in them), 7065, 6677, 5016 slightly reversed. Other lines :—4924·1, 5197·8, 5234·7, 5276·2, 5284·2, 5316·8, 5363·0.

Compared with the previous half-year there is a decrease in the number of metallic prominences observed.

TABLE I-B.—LIST OF METALLIC PROMINENCES OBSERVED AT SRINAGAR. AUGUST 8—DECEMBER, 1915.

Date.		Time I.S.T.		Base.	Latitude.		Limb.	Height.	Remarks.
					North.	South.			
		H.	M.	°	°	°		"	
August	9	10	20	20	15	...	W	60	D_1, D_2.
	10	10	20	10	...	12	W	45	D_1, D_2, b_1, b_2, b_3, b_4, 6677 ; C displaced.
	11	10	20	20	...	24	W	30	D_1, D_2, b_1, b_2, 6677.
	19	9	55	...	...	17	W	15	D_1, D_2, C displaced.
	23	...		...	14—25	...	W	15—40	D_1, D_2, b_1, b_2, b_3, b_4, 6677.
	29	8	45	4·5	...	22	E	45	D_1, D_2, b_1, b_2, b_3, b_4.
September	8	9	27	...	...	26·5—29·5	W	20	D_1, D_2, b_1, b_2, b_3, b_4, 6677.
	20	9	14	3	10	...	E	25	D_1, D_2, b_1, b_2, b_3, b_4, 6677 ; C displaced.
		9	1	8	...	18·5	W	70	D_1, D_2, b_1, b_2, b_3, b_4, 6677 ; C displaced.
	22	10	0	...	18·5—21	...	E	25	D_1, D_2, b_1, b_2, b_3, b_4, 6677.
October	6	9	30	7	14·5	...	E	45	D_1, D_2, b_1, b_2.
	20	10	5	0·5	10	...	W	20	D_1, D_2, b_1, b_2, b_3, b_4, 6677, C displaced.
	29	10	0	2	...	16·5	W	45	6677 faint, D_1, D_2, b_1, b_2, b_3, b_4 very faint.
	30	11	15	6	...	11	W	50	D_1, D_2, b_1, b_2, b_3, b_4, 5316, in two places ; C displaced.
November	9	16	15	13	...	8	E	...	D_1, D_2, b_1, b_2, b_3, b_4, 6677, eruptive ; C displaced.
	13	9	0	20·5	...	19	E	45	D_1, D_2, b_1, b_2, b_3, b_4, 6677 ; in southern half only ; C displaced.
	17	16	0	2	...	22·5	E	25	D_1, D_2, b_1, b_2, b_3, b_4, 6677, 5316, 5018, 4924 and other green lines ; C displaced.
	18	11	0	7	21	...	W	25	D_1, D_2, b_1, b_2, b_3, b_4, 6677 ; C displaced.
	23	9	37	1	...	15·5	W	20	D_1, D_2, b_1, b_2, b_3, b_4, 6677 ; C displaced.
	25	11	15	5	...	20	W	25	6677 faint ; C displaced.
		14	25	...	...	20	W	...	D_1, D_2, b_1, b_2, b_3, b_4, 6677 faint.
	26	9	50	10	...	20·5	W	180	6677 faint but bright at 11^h 12^m; C displaced.
December	1	12	30	...	19·5	...	E	...	D_1, D_2, 6677 ; not visible in C.

Displacements of the hydrogen lines.

The displacements observed at Kodaikanal are given in Table II-A and those observed at Srinagar in Table II-B.

TABLE II-A.—DISPLACEMENT OF THE C LINE IN PROMINENCES OBSERVED AT KODAIKANAL.
JULY TO DECEMBER, 1915.

Date.		Time.		Latitude.		Limb.	Displacement.			Remarks.
				N.	S.		Red.	Violet.	Both ways.	
1915.		H.	M.	°	°		A.	A.	A.	
July	2	9	2		18·5	W	1·5			
	3	8	32		20	W	1	3		
	6	8	37		17	E		Slight		
		8	22		24	W	0·2			
	8	9	0		21·5	W		1		Metallic.
	10	8	50	19		E	0·5			
	11	8	32	20		E	Slight			
		8	32	17		E		Slight		
	17				20	W		Do.		
	29	9	20		19	E	Slight	0 5		
				22·5		W	0·5			
August	6	8	40	43·5		W	Slight			
	8	10	10		35·5	W		2		
	9	9	52		14	W		1·5		
	10	8	44		30	E	1·5			
		8	22	37		W	1·5			
		9	5		26	W	3·5			
	12			20·5		W	2			
	15				22	E		2		
	16	9	20		35	W	Slight			
	19	8	45		27	E	1	Slight		
		8	45		32	E	4			At top
							2			At base.
		8	55		32	W	Slight			
	20	9	5		29·5	W	Do.	1		To red at base ; to violet at top.
	21	8	59	66		E		Slight		No prominence.
	22	9	27	35·5		E		0·5		At top.
					18·5	W	1			
	27	10	38		20·5	W	1·5			At top.
	28	8	35		52·5	E		Slight		
	29	8	50	23		E		2		Metallic.
September	9	9	25		37	E	Slight	Slight		To violet at base ; to red at top.
	14	8	35		29	W		Slight		
					34	W			Slight	
	15	8	45		21	E	1·5			
					27·5	E		1·0		
	19	9	50		35	E		Slight		
	21	9	58		12	W			Slight	
	23	9	16	10		W	Slight			
		9	15	19		W	1	0·5		
	26	9	10	72·5		E	0·5			Metallic.
					21	E	0·5			
October	2	8	28		19	E		Slight		
	3	8	27	11		W	Slight			
	4	9	0		25·5	W		Slight		At base.
	5	8	34	56·5		E		Do.		At top.
			26	12·5		E	1			
			21		37	E		0·3		At top.
			42		24	W	2			No prominence.
			47	43		W	0·5	Slight		To red at top ; to violet at base.
	6	8	45	18		E	Slight			
	7	8	43	10		E			Slight	
	8	8	16	8		E		Slight		At top.
			34	18		W			Slight	
	12	8	40	71·5		E		Slight		
			35		79	E	Slight			
	13	8	35		21	E	Do.			At top.
	14	8	45		15·5	E	Do.			Do.

Date.		Time.		Latitude.		Limb.	Displacement.			Remarks.
				N.	S.		Red.	Violet.	Both ways.	
1915.		H.	M.	°	°		A.	A.	A.	
October	22	8	51	44·5		E		Slight		No prominence.
			46	14		E		1		
			43		2	E		Slight		No prominence.
			40		84	E	Slight			Do.
			59		27	W	Do.			At base.
	23	8	34		25	W		0·5		Do.
	24	9	0		13·5	W	2	2		Displacement changing rapidly in amount.
	26	8	25		18	E		Slight		No prominence.
	29	11	20		16·5	W	1	2		To red at base; to violet at top.
	31	9	30	20·5		E	1			
November	3	8	35	36·5		W	0·5	0·5		
	9	8	49		8	E	2	3		Displacement changed rapidly.
			34	27·5		W	Slight			
	17	8	32		18	E		0·5		At base.
	20	8	54	20		E		0·5		
	21	8	35	35·5		E	Slight	Slight		To red at top; to violet at base
	24				17	W	2			
	25	9	0		21	W	1	3		
	26	9	38	12		W		1·5		At top.
	28	9	34		58	E		0·5		Over whole prominence.
	30	...			29	W		0·5		At top.
December	1	9	4	12		W	Slight			At base.
	2	9	4	27·5		W	1			Do.
	5	8	26		56	E	Slight			No prominence.
			45	10		W	Do.			Do.
	6	9	5	37·5		E	0·5			At top.
			0		38	W			Slight	Widened symmetrically.
		8	56	15		W		Slight		At top.
			46	59		W		Do.		
	7	8	40		28	E		Do.		At top.
	9	8	22		20·5	E	Slight			Do.
	10	8	39	88		E		Slight		No prominence.
		9	20		52	E	Slight			
		8	46		23·5	W			Slight	
			45		15	W		Slight		
	11	8	42	49		E				No prominence.
			37		26	E		Slight		At top.
			46		34	W	Slight			At base.
	12	8	34	17		W	Do.			
	13	8	34	68		E	Do.			C bulging out to red over 2°.
				16·5		W	Slight			
	14	8	40		12	W	Do.			No prominence.
	15	8	33		67	E		Slight		Do.
			56	10		W		Do.		
			59	24		W	Slight	Do.		To red at base; to violet at top.
	16	8	32	18		W	0·5			At top.
	17	8	49		33	E	Slight			
			34	12		W	Do.			At base.
			37	44		W		Slight		No prominence.
	23	8	53	12·5		W		Do.		
	30		55		25·5	E		Do.		
	31		47		56	E		Do.		At base.

There was a large decrease on the previous half-year in the number of displacements observed at Kodaikanal. There were 47 in the northern hemisphere and 62 in the southern; there were 54 in the eastern hemisphere and 55 in the western. Fifty-six displacements were to the violet, 61 to the red and 7 both ways simultaneously.

Between 0° and 30° of latitude there were displacements observed at Kodaikanal in 73 prominences, between 31° and 60° in 28, and between 61° and 90° in 8.

TABLE II-B.—DISPLACEMENT OF THE C LINE IN PROMINENCES OBSERVED AT SRINAGAR. AUGUST 8TH TO DECEMBER, 1915.

Date.		Time.		Latitude.		Limb.	Displacement.			Remarks.
				N.	S.		Red.	Violet.	Both ways.	
1915.		H.	M.	°	°		A.	A.	A.	
August	10	10	20		12	W	Slight	Slight		Metallic.
	12	11	30	30		E		1		
	15	9	33		21·5	E	0·5			At bases of the two bright streaks.
		9	10	25·5		W		2		
	16	10	34		19	W		Slight		No prominence.
					17	W			Slight	Do.
	18	9	0	32·5		E	1			At northern end.
	19	9	55		17	W	1			D_3 also displaced; metallic.
	20	9	20		28·5	W	Slight	Slight		To red at northern end; to violet at southern end.
	28	9	20	18·5		E		1		Near top.
		8	41	53·5		W		Slight		Except near base.
September	1	9	30		24	W		Do.		Over taller streaks at northern end.
	3	8	45	22		E			2	At northern end. Displacement gone at 8h 52m.
	7	8	50		38·5	E	1			
	8	9	27		26·5	W		0·5		
	10	9	58	81		W			Slight	No prominence.
	12	9	10		17	E	Slight			Do.
		9	30		35	W		1		On northern side.
		9	30		23	W		Slight		At northern end.
	15	10	28		29	W	2			
			28		31	W	2			
	16	9	30		15·5	W		1		On southern jet.
	19	8	30	21		E	1			At northern end.
		8	30	14·5		E	1		4	At base.
	20	9	14	10		E		2		Metallic.
		9	1		18·5	W				At base of tall streak; displacement to red gone at 9h 3m.
	26	9	30		23·5	E	Slight			At base.
		10	8		23·5	E		2		Over whole prominence.
	29	10	33		32·5	E	1			In places.
October	5	11	48	10·5		E	0·5			At base.
	7	9	30	22		E	2			
		11	42	10·5		E	3	2		To red over lower part; to violet in upper streak.
		9	40	18		E	2			Over whole height (170″).
		9	45	18		E		1		At base of stem.
		9	50	18		E	5			At northern end of top.
		10	5	18		E	2-3	2-3		To red on northern bright branch; to violet on southern faint branch. Displacement to violet over whole prominence from 10h 40m to 11h 42m.
	8	10	40	56·5		E		Slight		
	12	10	0		45·5	W	Slight			
	13	9	43	31·5		E	Do.			
		9	38		14·5	E			1	No prominence.
	16	9	55	27		E	2			At base.
	19	9	15	18		E			Slight	No prominence at 9h 15m. Prominence (15″) at 10h 7m.
	20	10	5	10		W		1		Metallic; no displacement at 10h 20m.
	26	...		21		W	0·5			At base.
	28	...		33·5		E	1	1		To red at northern end; to violet at southern end.
	30	9	40		11	W	1-1·5			At southern end; over a spot; metallic at 11h 15m.
November	4	10	9		15	E	0·5	0·5		To red in upper half; to violet in lower half.
	7	16	10	57·5		W		0·5		At top and in base.

Date.		Time.		Latitude.		Limb.	Displacement.			Remarks.
				N.	S.		Red.	Violet.	Both ways.	
1915.		H.	M.	°	°		A.	A.	A.	
November	9	10	20		8	E	1·5			
		11	32		8	E		1		Metallic, at $16^h\ 15^m$.
		9	35		22·5	E		2		At northern end.
	13	9	0	19		E	Slight	Slight		Metallic ; to red near base, to violet near top at + 14° E.
	16	8	50	87		E	0·5			
	17	9	32		22·5	E	1	Slight		To red at northern end ; to violet at southern end.
		16	0		22·5	E	1—2			Metallic.
	18	9	52		23	E	1			No prominence.
		11	0	21		W	1	0·5		Metallic.
	22	9	54		54·5	W		Slight		
	23	...			63	E		Do.		
		9	37		15·5	W	Slight			At base ; metallic.
		10	20		15·5	W	1	1·5		To red at southern end ; to violet at northern end.
		10	25		4·5	W	1·5			Over slanting streak at northern end.
		11	15	59·5		W	1			
		11	50	59·5		W		2—3		
	24	9	49		29	E	Slight			No prominence.
	25	10	40		29	W	1	1		To red in upper half ; to violet in lower half.
		10	45		20	W	1	Slight		
		11	15		20	W		Do.		Over a short bright streak ; metallic at $15^h\ 30^m$.
		16	0		21	W			2	
		16	0		27	W		0·5		
	26	11	5	13·5		W			3	At base ; smaller displacements observed from $9^h\ 50^m$ to $14^h\ 40^m$ in other parts of prominence ; metallic.
	28	11	24	66·5		E		Slight		No prominence.
December	2	10	45	26		E	0·5			At base.
	5	9	20	38·5		E		Slight		In southern part.
	7	11	7		28	E		Do.		On northern edge.
	8	10	40		18	E			Slight	On lower bright part.
		10	58		26	W				In chromosphere.
	9	14	30	11·5		E	Slight	Slight		Near base in southern half.
	24	9	42	7·5		W		Do.		
				10		W	Slight			

Of the 71 prominences in which displacements were observed at Srinagar, 33 were in the northern hemisphere and 38 in the southern ; there were 37 in the eastern hemisphere and 34 in the western. Forty displacements were to the violet, forty-three to the red and nine both ways simultaneously.

Between 0° and 30° of latitude there were displacements observed at Srinagar in 54 prominences, between 31° and 60° in 13, and between 61° and 90° in 4.

At both Kodaikanal and Srinagar the greatest number of displacements occurred between 0° and 30° ; this is apparently characteristic of times of great spot activity.

Reversals and displacements of the C line on the disc.

One hundred and eighty reversals of the C line, 22 darkenings of the D_3 line and 66 displacements of the C line were observed at Kodaikanal near spots. There is a decrease on the previous half-year in all these. Their distribution east and west of the central meridian is given below :—

		East.	West.
Kodaikanal ...	Reversals of C near spots	80	100
	Darkenings of D_3	9	13
	Displacements of C	39	27

There was again a large preponderance of displacements towards the red, 46 being to the red and 6 to the violet.

At Srinagar there were observed 56 reversals of the C line, 5 darkenings of the D_3 line and 21 displacements of the C line near spots. Their distribution east and west of the central meridian was as follows :—

		East.	West.
Srinagar ...	Reversals of C near spots	28	28
	Darkenings of D_3	3	2
	Displacements of C	10	11

Prominences projected on the disc as absorption markings.

The grating spectroheliograph for photographing the absorption markings in "$H\alpha$" light was in regular use during the six months. Photographs were obtained on 85 days which were counted as 63 effective days. The mean daily area in millionths of the sun's visible hemisphere, corrected for foreshortening and for imperfect observations, and the mean daily numbers are given below :—

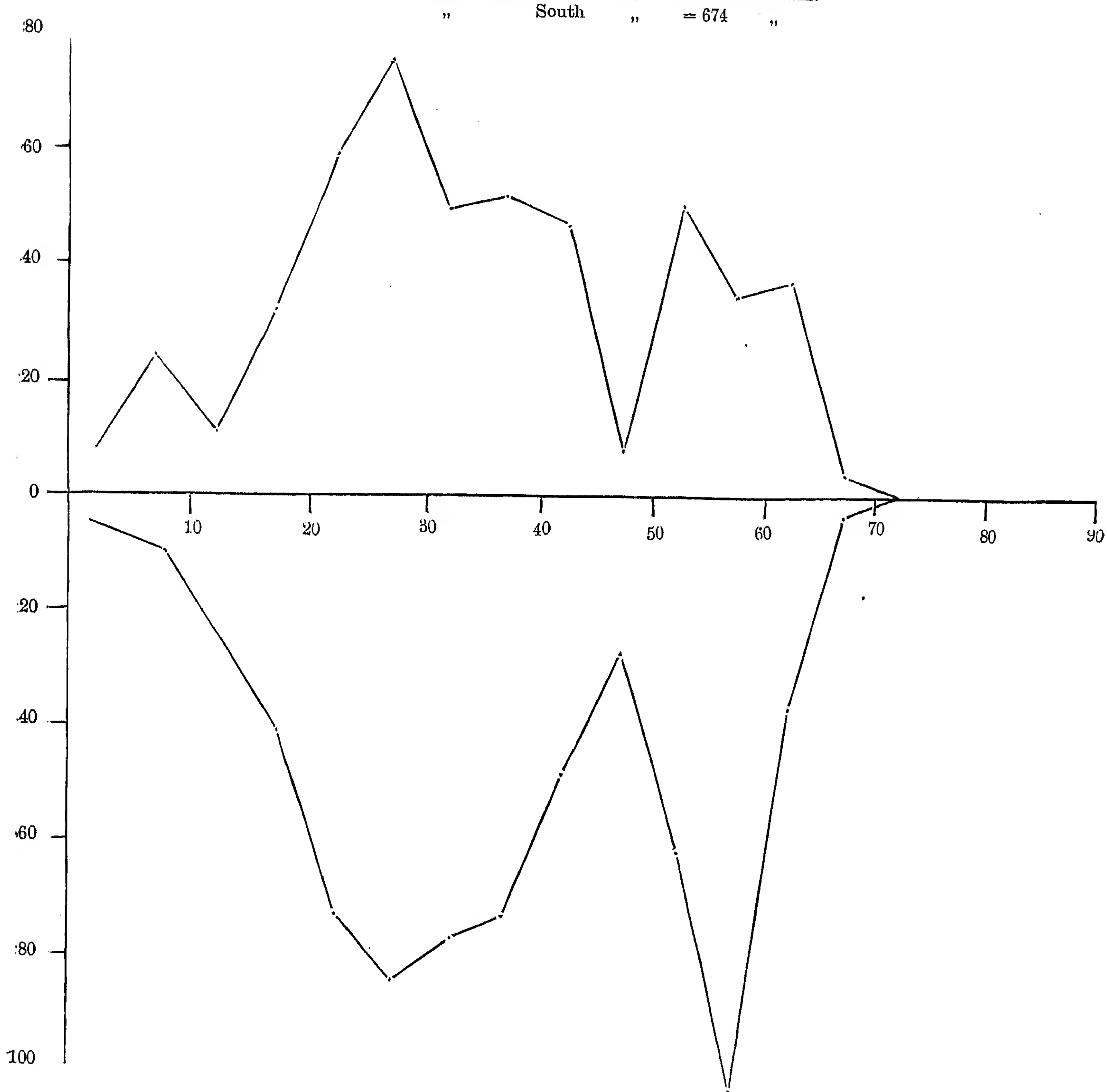
	1915, July—December. Areas.	Numbers.
North	492·0	4·7
South	673·9	6·0
Total ...	1,165·9	10·7

There has been an increase in the number observed but a decrease in the areas resulting from a smaller average area of each marking.

The distribution in latitude is given in the accompanying diagram, and is essentially similar to that in the previous six months of the year.

FIG. 2.—MEAN AREAS OF Hα ABSORPTION MARKINGS—
JULY 1 TO DECEMBER 31, 1915.

Total mean area for north hemisphere = 492 millionths.
" South " = 674 "



There was a preponderance of Hα markings on the eastern side of the central meridian, the percentage east being 55·80 in areas and 53·63 in numbers.

THE OBSERVATORY, KODAIKANAL,
31st March 1916.

T. ROYDS,
Assistant Director.

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BULLETIN No. LI

NEW MEASURES OF RADIAL MOTION IN SUNSPOTS.

BY J. EVERSHED, F.R.S.

During the years of minimum sunspot activity, very few opportunities have occurred at Kodaikanal for extending knowledge of the movements taking place in spots, beyond what could be gathered from the first series of sunspot spectra obtained in the year 1909, which led to the discovery of the radial movement. It was realized that in order to make any advance it was useless to attempt to photograph spot spectra under conditions of poor definition of the spot on the slit of the spectrograph. Also, when definition was at its best, means must be employed for reducing the exposure time to the minimum possible consistent with high dispersion, in order to get clear spectrum images of details of the spots themselves.

Early in 1915 it was found possible to reduce greatly the exposure times by employing the new Anderson grating, which has a much larger ruled area than either of the gratings previously used, and is also very bright in the third order. In addition, the Observatory had acquired on loan from the Nizamiah Observatory a lens of 15 inches diameter and 15 feet focus, which I mounted temporarily on a moving carriage running on rails passing in front of the siderostat, so that when other apparatus was not in use the lens could be run into position in front of the siderostat mirror, giving an image of the sun about 40 mm. diameter on the slit of the spectrograph. This lens was found to be more efficient in the blue and violet part of the spectrum than the parabolic silver-on-glass mirror previously employed, and the solar image given by it was also larger, and needed no secondary magnifier. The spectrograph itself, it may be stated, magnifies the image about twice.

In order to get spectral images representing central sections of a spot, a very simple guiding arrangement was constructed. This consists of a plane parallel quartz plate, about 1 cm. thick, or of a glass cell with plane parallel sides, containing an absorbing solution, which is placed immediately in front of the slit. This plate or cell is mounted so that it can be inclined, either in a vertical or a horizontal plane, the movement being controlled by a handle conveniently placed near the eye-piece of a telescope, in which may be observed the first or second order spectrum while photographing the third or fourth order. The spot image is first brought as near to the slit as possible by means of the siderostat slow motions ; then it is moved horizontally or vertically to any desired position on the slit by inclining the quartz plate or absorbing cell, which thereby moves the image without altering the direction of the rays of light falling on the grating. If long exposures are required, the spot may be kept from wandering in any direction during the exposure by this device, but for short exposures it is merely required to place the spot correctly on the slit.

The image-rotating device described in the Memoirs of the Kodaikanal Observatory, Vol. I, part 1, was also used. This consists of a large total-reflection prism, mounted on a horizontal axis, and with its hypotenuse face in a vertical plane. The light falls normally on one side of the face, and is totally reflected twice, emerging from the other side of the face; it is then reflected on to the slit by a second mirror. The rotation of the prism through any angle produces a rotation of the image on the slit plate of twice that angle. It is used to adjust the image so that the slit may bisect a spot in a direction passing through the centre of the sun's disk, or in a direction at right angles to that. I call these sections "radial" and "tangential" respectively.

With these arrangements a beautiful series of spectra was secured at Kodaikanal of the spot which crossed the visible disk of the sun between March 29 and April 12, 1915, in latitude 21° north,[1] the sky conditions during that period proving very favourable in the early morning hours. (See plate III.)

Of the series of plates obtained eleven have been measured, and the others have been carefully examined under the micrometer microscope. The spectra obtained with a radial slit show larger displacements than have been measured in any spot spectra hitherto photographed. Assuming the displacement to represent motion in the line of sight, parallel to the surface of the sun, the largest mean velocity measured for a number of lines of intensity 1 is 3·52 km/sec., on the west side of the spot; and for two of the lines, viz., 4726·3 and 4729·2 it amounts to 4 km/sec. On the east side the movement is smaller, being only about half as much as on the west. Most of the spectra taken with a tangent slit also show some evidence of motion, which will be discussed later. The point I wish to emphasize here is that the displacements are larger with good definition of the penumbral image than would have been the case with an image more or less diffused along the slit by poor definition or long exposure time; it is not considered that this particular spot was an unusually active one. The exposure times in this series of spectra range from five to thirty seconds for lantern plates, varying with the distance of the spot from the centre of the disk, and with the region of spectrum. For Wratten "Instantaneous" plates, exposures could be reduced to a fraction of a second, but the contrast in these is less satisfactory than in the lantern plates, partly, I believe, from a defect in the grating, which, notwithstanding the extreme faintness of the third order ghosts, gives less good contrast than the Rowland grating, in which the ghosts are more obtrusive in emission spectra.

The spectra were measured by means of a single straight spider thread in the micrometer eye-piece. This was placed as nearly parallel as possible to the spectrum lines on either side of the spot image. Each line selected for measurement was then bisected at four points as seen in the field of the microscope, as follows :—

(1) In the undisturbed photosphere spectrum, above the spot band.

(2) Near the outer limit of the upper penumbra.

(3) Near the outer limit of the lower penumbra.

(4) In the undisturbed photosphere spectrum, below the spot band.

The positions (1) and (4) were measured at the same distance above and below the centre of the spot, and the penumbral measures are referred to the mean of the photosphere measures, to eliminate a systematic error which would arise from a want of parallelism between the spider thread and the spectrum lines. As the thread was adjusted so as to give very small differences between the upper and lower photosphere measures, any outstanding error due to the small distance of the penumbræ from the centre of the spot became insignificant, and not worth the labour of correcting. This error would tend to increase the shifts on one side of the spot relative to those on the other, but would not affect the sum of the shifts. As is the usual practice, the spectra were each measured twice, viz., with the red end of the spectrum to the right, and left, respectively. This method of measuring is the simplest for obtaining separate values of the displacements for the east and west edges of spots; but more accurate values of the relative shifts of the different lines could be obtained by the positive on negative method, or by the method of juxtaposing the two opposite edges of the spot, as described by Dr. St. John.[2]

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[1] Greenwich No. 7223.

[2] Astrophysical Journal XXXVII, 322.

For most of the images, the lines selected for measurement were limited to well defined Fe lines of intensities ranging from 0 to 6 of Rowland's scale ; but in the plate giving the largest shifts some lines of Ni, Cr, and Ti were also measured.

Radial movements in east and west penumbræ.—I will discuss first the series of spectra obtained with the radial slit, and therefore giving the displacements due to the radial movement of the spot vapours. In the following tables are given the observed velocities in the line of sight derived from the displacements of the Fe lines, in a spot which crossed the meridian on April 4–5, 1915, in north latitude 20°·7. Table I represents a plate exposed on April 3, with the spot east of the central meridian, and this is followed in tables II and III by measures of spectra photographed on April 6 and 7, when the spot was west of the central meridian. On the 6th, three radial sections of the spot were photographed (table II a, b, and c). a and b are each through the wider part of the umbra, but as they show systematic differences of velocity, they are treated separately. c represents a parallel section through a narrower part of the umbra.

MOVEMENTS IN PENUMBRÆ DERIVED FROM FE LINES GROUPED ACCORDING TO INTENSITY.

TABLE I.

Date 1915, April 3.
Latitude of Spot (on central meridian) + 20°·7.
Central Distance (sun's radius = 1) 0·589 east.
Slit radial.

λ	Intensity.	East Penumbra km/sec.	West Penumbra km/sec.	λ	Intensity.	East Penumbra km/sec.	West Penumbra km/sec.
4695·402	1	+ 1·70	− 1·15	4690·317	4	+ 1·38	− 1·20
4701·231	1	+ 1·65	− 0·64	4703·131	4	+ 1·55	− 1·19
4705·641	0	+ 1·10	− 1·46	4728·732	4	+ 1·18	− 1·18
4711·665	0	+ 2·00	− 0·95	4731·637	4	+ 1·35	− 0·85
4726·327	0	+ 1·71	− 1·85	4733·779	4	+ 0·85	− 0·54
4729·207	1	+ 1·48	− 1·08	4745·992	4	+ 1·33	− 0·98
Means for intensity 0 and 1.		+ 1·61	− 1·19	4748·325	4	+ 1·20	− 1·33
4721·179	2	+ 1·31	− 1·18	4773·007	4	+ 0·73	− 0·61
4757·771	2	+ 1·28	− 1·23	Means for intensity 4		+ 1·19	− 0·98
Means for intensity 2		+ 1·29	− 1·20	4707·457	5	+ 1·10	− 1·05
4709·271	3	+ 1·32	− 1·14	4736·963	6	+ 0·18	− 0·62
4710·471	3	+ 0·77	− 0·82	Means for intensities 5 and 6.		+ 0·64	− 0·83
4736·031	3	+ 1·21	− 1·03				
4741·718	3	+ 1·34	− 0·62				
4744·573	3	+ 1·69	− 1·07				
Means for intensity 3		+ 1·26	− 0·94				

Reduced to horizontal movement, the mean velocities are :—

Line intensity.	East Penumbra km/sec.	West Penumbra km/sec.
0 and 1	+ 2·73	− 2·02
2	+ 2·19	− 2·04
3	+ 2·14	− 1·59
4	+ 2·02	− 1·66
5 and 6	+ 1·09	− 1·41

TABLE IIa.

Date 1915, April 6.

Latitude of Spot (on central meridian) 20°·7.

Central Distance (sun's radius = 1) 0·513 west.

Slit radial through wider part of umbra.

λ	Intensity.	East Penumbra km/sec.	West Penumbra km/sec.	λ	Intensity.	East Penumbra km/sec.	West Penumbra km/sec.
4615·743	1	− 0·66	+ 1·33	4607·831	4	− 0·43	+ 1·09
4620·693	1	− 0·38	+ 1·56	4618·971	4	− 0·66	+ 1·13
4634·895	1	− 0·61	+ 2·06	4630·306	4	− 0·33	+ 0·98
4662·149	1	− 0·69	+ 1·28	4638·193	4	− 0·37	+ 0·93
Means for intensity 1		− 0·58	+ 1·56	4643·645	4	− 0·42	+ 1·35
4587·308	2	− 0·53	+ 1·11	4647·617	4	− 0·18	+ 0·74
4595·540	2	− 0·43	+ 1·11	Means for intensity 4		− 0·40	+ 1·04
4604·735	2	− 0·38	+ 1·43	4603·126	6	− 0·24	+ 0·81
4636·027	2	− 0·56	+ 1·21	4625·227	5	− 0·28	+ 1·13
Means for intensity 2		− 0·47	+ 1·21	4629·521	6	− 0·56	+ 1·22
4598·303	3	− 0·43	+ 0·87	4637·685	5	− 0·28	+ 0·99
4602·183	3	− 0·29	+ 1·10	4679·027	6	− 0·45	+ 0·95
4613·386	3	− 0·47	+ 1·00	Means for intensity 5 and 6.		− 0·36	+ 1·04
4619·468	3	− 0·19	+ 1·19				
4669·354	3	− 0·46	+ 1·13				
Means for intensity 3		− 0·37	+ 1·13				

Reduced to horizontal movement, the mean velocities are :—

Line intensity.	East Penumbra km/sec.	West Penumbra km/sec.
1	− 1·13	+ 3·04
2	− 0·92	+ 2·36
3	− 0·72	+ 2·20
4	− 0·78	+ 2·02
5 and 6	− 0·70	+ 2·02

TABLE IIb.

The same date and spot as in Table IIa, but another plate in a different region of spectrum.

Slit radial, through wider part of umbra.

λ	Intensity.	East Penumbra km/sec.	West Penumbra km/sec.	λ	Intensity.	East Penumbra km/sec.	West Penumbra km/sec.
4695·042	1	− 0·79	+ 1·53	4688·357	2	− 0·65	+ 1·57
4701·231	1	− 0·55	+ 1·75	4721·179	2	− 0·73	+ 1·95
4705·641	0	− 0·78	+ 1·79	4757·771	2	− 0·84	+ 1·77
4711·665	0	− 0·96	+ 1·69	Means for intensity 2		− 0·74	+ 1·76
4726·327	0	− 1·13	+ 2·03				
4729·207	1	− 0·90	+ 2·07				
Means for intensity 0 and 1		− 0·85	+ 1·81				

λ	Intensity.	East penumbra km/sec.	West penumbra km/sec.
4709·271	3	− 0·91	+ 1·46
4710·471	3	− 0·46	+ 1·00
4736·031	3	− 0·94	+ 1·66
4741·718	3	− 0·89	+ 1·34
4744·573	3	− 0·94	+ 1·79
Means for intensity 3		− 0·83	+ 1·45

λ	Intensity.	East penumbra km/sec.	West penumbra km/sec.
4690·317	4	− 0·93	+ 1·67
4705·131	4	− 1·24	+ 1·47
4728·732	4	− 0·58	+ 1·49
4731·651	4	− 0·63	+ 2·02
4733·779	4	− 0·36	+ 1·17
4745·992	4	− 0·80	+ 1·69
4748·325	4	− 1·11	+ 1·73
4773·007	4	− 1·00	+ 1·09
Means for intensity 4		− 0·83	+ 1·54
4707·457	5	− 0·46	+ 1·15
4736·963	6	− 0·72	+ 0·59
Means for intensity 5 and 6.		− 0·59	+ 0·87

Reduced to horizontal movement, the mean velocities are :—

Line intensity.	East penumbra km/sec.	West penumbra km/sec.
0 and 1	− 1·65	+ 3·52
2	− 1·44	+ 3·42
3	− 1·62	+ 2·82
4	− 1·61	+ 3·00
5 and 6	− 1·15	+ 1·69

TABLE IIc.

The same date and spot as in Table IIa and b.
Slit radial, through narrower part of umbra.

λ	Intensity.	East penumbra km/sec.	West penumbra km/sec.
4615·743	1	− 0·76	+ 1·85
4620·695	1	− 0·52	+ 1·75
4634·895	1	− 0·65	+ 1·17
4662·149	1	− 0·92	+ 1·19
Means for intensity 1		− 0·71	+ 1·49
4587·135	2	− 0·63	+ 1·35
4595·540	2	− 0·63	+ 1·02
4604·735	2	− 0·67	+ 1·47
4636·027	2	− 0·61	+ 1·45
Means for intensity 2		− 0·63	+ 1·32
4598·303	3	− 0·43	+ 1·30
4602·183	3	− 0·53	+ 1·15
4613·386	3	− 0·52	+ 1·76
4619·468	3	− 0·43	+ 1·33
4669·354	3	− 0·73	+ 1·19
4683·745	3	− 0·58	+ 1·72
Means for intensity 3		− 0·54	+ 1·16

λ	Intensity.	East penumbra km/sec.	West penumbra km/sec.
4584·018	4	− 0·33	+ 0·73
4607·831	4	− 0·52	+ 0·95
4618·971	4	− 0·80	+ 1·00
4630·306	4	− 0·52	+ 1·12
4638·193	4	− 0·42	+ 1·07
4643·645	4	− 0·42	+ 1·16
4647·617	4	− 0·42	+ 0·70
Means for intensity 4		− 0·49	+ 0·96
4603·126	6	− 0·43	+ 0·57
4625·227	5	− 0·66	+ 1·08
4629·521	6	− 0·75	+ 1·03
4637·685	5	− 0·42	+ 1·12
4679·027	6	− 0·41	+ 1·18
Means for intensity 5 and 6.		− 0·53	+ 1·00

Reduced to horizontal movement, the mean velocities are :—

Line intensity.	East penumbra km/sec.	West penumbra km/sec.
1	− 1·37	+ 2·90
2	− 1·23	+ 2·57
3	− 1·05	+ 2·26
4	− 0·95	+ 1·86
5 and 6	− 1·03	+ 1·95

TABLE III.

Date—1915 April 7.
Latitude of Spot +20°·7 (on central meridian).
Central Distance (sun's radius = 1) 0·617 west.
Slit radial.

λ	Intensity.	East penumbra km/sec.	West penumbra km/sec.	λ	Intensity.	East penumbra km/sec.	West penumbra km/sec.
4542·600	1	− 1·06	+ 2·08	4508·455	4	− 0·64	+ 1·48
4545·311	1	− 0·96	+ 2·22	4584·018	4	− 0·61	+ 1·26
4566·693	1	− 0·76	+ 2·47	4607·931	4	− 0·33	+ 1·80
4574·396	1	− 1·23	+ 2·36	4618·971	4	− 1·32	+ 1·70
4615·743	1	− 0·57	+ 2·03	4630·306	4	− 0·42	+ 1·72
4620·693	1	− 1·80	+ 1·83	4638·193	4	− 0·14	+ 1·90
4634·895	1	− 1·07	+ 2·09	4643·645	4	− 0·74	+ 2·13
Means for intensity 1		− 0·92	+ 2·15	4647·617	4	− 0·23	+ 1·29
4560·266	2	− 0·67	+ 2·24	Means for intensity 4		− 0·55	+ 1·66
4574·899	2	− 0·66	+ 1·75				
4587·308	2	− 0·80	+ 1·96	4603·126	6	− 0·48	+ 0·81
4595·540	2	− 1·07	+ 1·49	4625·227	5	− 0·47	+ 1·92
4636·027	2	− 0·70	+ 1·86	4637·685	5	− 0·37	+ 1·77
Means for intensity 2		− 0·78	+ 1·86	Means for intensity 5 and 6.		− 0·44	+ 1·50
4515·508	3	− 0·39	+ 1·82				
4520·397	3	− 0·84	+ 1·82				
4546·129	3	− 0·52	+ 1·50				
4548·024	3	− 0·48	+ 1·44				
4556·063	3	− 0·57	+ 1·87				
4598·303	3	− 0·84	+ 1·53				
4602·183	3	− 0·38	+ 1·42				
4619·468	3	− 0·66	+ 1·65				
4669·354	3	− 0·64	+ 1·68				
4683·745	3	− 0·54	+ 1·89				
Means for intensity 3		− 0·58	+ 1·66				

Reduced to horizontal movement, the mean velocities are :—

Line intensity.	East penumbra km/sec.	West penumbra km/sec.
1	− 1·49	+ 3·48
2	− 1·26	+ 3·02
3	− 0·93	+ 2·69
4	− 0·89	+ 2·69
5 and 6	− 0·71	+ 2·43

It is remarkable that when east of the central meridian the eastern penumbra gives the larger velocity, but when west of the meridian, the velocities are larger in the western penumbra. The largest displacements were thus always found on the limb side of the spot in this series of measures. This may be an accidental circumstance, although the same phenomenon appears on some of my previous measures. It is evidently of importance to measure the shifts on the limb and centre side of a spot separately.

In table IV, I give the mean velocities on each side of the spot, when east, and when west, of the central meridian; from this it is seen that the preponderance of velocity on the limb side of the spot is much more marked when the spot was west than when it was east.

TABLE IV.

—	Line intensity.	East Penumbra km/sec.	West Penumbra km/sec.	—	Line intensity.	East Penumbra km/sec.	West Penumbra km/sec.
Spot east of C.M. (one set of measures).	0 and 1	+ 2·73	− 2·02	Spot west of C.M. (four sets of measures).	0 and 1	− 1·41	+ 3·23
	2	+ 2·19	− 2·04		2	− 1·21	+ 2·84
	3	+ 2·14	− 1·59		3	− 1·08	+ 2·49
	4	+ 2·02	− 1·66		4	− 1·06	+ 2·39
	5 and 6	+ 1·09	− 1·41		5 and 6	− 0·90	+ 1·98

The velocities found in the penumbræ of spots generally increase with the distance from the centre of radiation, the motion being zero at some point in the umbra, and accelerating outwards.[1] An unsymmetrical spot, therefore, might be expected to give the greater velocities where the penumbra is more extended. On April 3, the widths of penumbræ were approximately 16,000 km. on the east side, and 13,000 km. on the west. As, on this date the velocity at the outer limits is greater on the east side, this is in accordance with the above statement; but on April 6 and 7, when the velocity on the west side is more than twice that on the east, this same inequality persists, and is greater than before, the east penumbra being about 19,000 km. in width, whilst the western penumbra is only 10,000 km. in a radial section.

The displacements at equal distances east and west of the umbra are therefore very unequal on April 6 and 7. This might conceivably be due to a proper motion of the spot as a whole, in a westerly direction. A forward movement equal to 0·9 km/sec would account for the difference of shifts between the east and west penumbræ. If this were the case, there would be a displacement towards red in the lines over the umbra, equivalent to 0·9 km/sec, which apparently there is not. The lines are here too faint for measurement, but as they are distinctly more inclined on the western penumbra than on the eastern, this points to an absence of appreciable shift in the umbra.

The eastern penumbra is much less definitely bounded than the western, and the outlying parts on the east side show no displacement on April 7, the greatest shift being found at a point about 9,000 km. within the outer limits of the penumbra (see fig. 1, page 174). At the point where the motion ceases, there is a slight rift in the penumbra, and it is the outer separating portion which shows no radial movement. This remarkable absence of movement has also been observed previously, when the radial slit has passed through a completely isolated patch of penumbra. It would seem that radial motion does not occur in penumbræ without an umbral centre.

On April 8th the radial slit passed through a completely detached penumbra on the east side and over this the lines are bent in the usual way indicating radial motion; the photoheliograph plate shows however that this penumbra is forming a secondary nucleus and constitutes a small satellite spot.

[1] This acceleration, indicated by the slant of the lines over the penumbræ, is well seen in all the spectra except in the east penumbra on April 6, in the section through the narrow part of the umbra. In this image the line appears to be as much displaced near the umbra as it is near the outer edge of the penumbra.

Another novel and interesting feature in the spectrum of this spot is the bending of the lines on the adjacent photosphere spectrum, clearly indicating movement outside the western penumbra. (See fig. 1. The bending of the lines outside the spot spectrum can also probably be made out in the half-tone reproduction in plate III.) On this side of the spot, the highest velocity occurs, as is normally the case, at the outer edge of the penumbra, where it reaches almost 4 km/sec for some of the weaker lines. Immediately beyond this point, on the photosphere outside, the lines assume their normal width, but not their normal position, for they curve sharply back to a point about 8,000 km. outside the penumbra, where they regain their normal wave-lengths. Although the radial motion is thus continued with diminishing velocity far outside the penumbra, there is nevertheless, a very marked kink in the line, or change of velocity, at the penumbral limit. For lines of intensity 4, the appearance is as in fig. 1 excepting that the lines over the spot are less dark and their edges much more diffuse than in the woodcut.

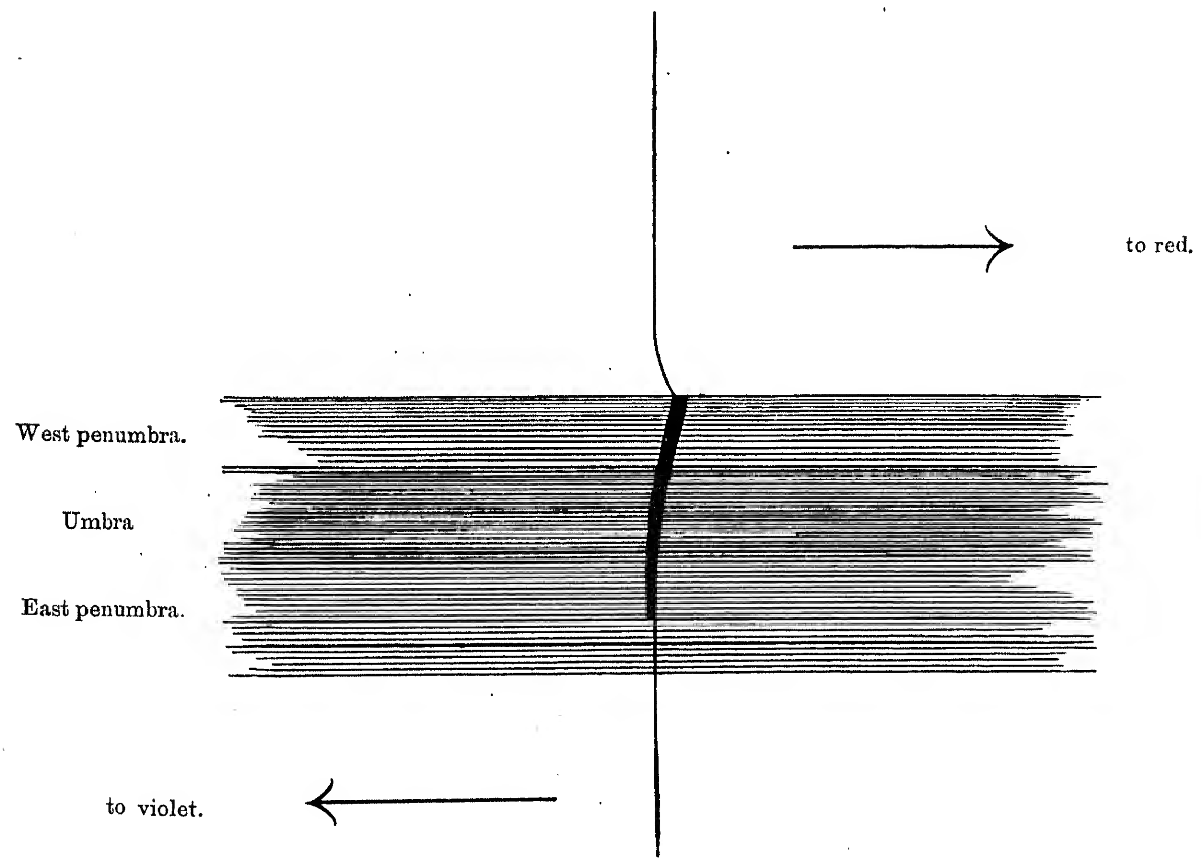

Fig. 1. Course of Fe line crossing spot—April 7, 1915.

Outside the spot, the lines are of normal width right up to the edge of the penumbra, where there is a sudden bend or shoulder. Inside the penumbra, they are in some cases twice the normal width, with a tendency to diffusion in the direction of displacement, indicating velocities still higher than those measured for a portion of the absorbing gas. The shoulder-like bend is best seen in lines of intensity 3 and 4 ; in weaker lines the curvature outside the penumbra is well seen, but the increase in width at the shoulder is not so evident.

The curvature of the lines is well seen in all the plates taken after the meridian passage of the spot, viz., on April 6, 7, 8 and 9. It is also indicated in the spectra of April 3.

Radial motion in relation to line intensity.—The mean velocities obtained by averaging the results from east and west penumbræ do not vary much on the different dates when spectra of this spot were obtained. I therefore give in table V the mean results for all the five sets of measures detailed in tables I, II and III.

TABLE V.

Mean Velocities of East and West Penumbræ.

Line intensity.	Mean Velocity (5 sets of measures).
0 and 1	2·33 km/sec.
2	2·04 ,,
3	1·80 ,,
4	1·75 ,,
5 and 6	1·42 ,,

The velocities here shown do not differ materially from those obtained from the earliest radial motion plates measured by me in the year 1909.[1] They are however about 2·7 times larger than those found by St. John for the corresponding line intensities. These are from spectra photographed in the years 1910 and 1911 (see table VII "The Iron Scale" in his paper on "Radial Motion in Sunspots," Astrophysical Journal XXXVII, pages 332—353). This large discrepancy is probably mainly accounted for by the small size of the spots photographed by St. John, which averaged 34″ in diameter on the meridian, or roughly 25,000 km. across the radial section, whereas the spot of April 1915, corrected for foreshortening, was from 44,000 to 48,000 km. across the radial section, excluding the outer portion of the eastern penumbra which showed no motion.

As the velocities at the outer limits of the penumbræ are usually roughly proportional to the diameter of the spot, the spot of April 1915 should give nearly double the velocities found by St. John. My figures in table V may therefore be compared directly with those given in St. John's "Iron scale," which represent the sum of the velocities at the two edges of the spots, and are therefore twice the mean values of east and west penumbræ. The comparison shows a considerable outstanding discrepancy, my figures being about $1\frac{1}{3}$ times larger than St. John's. This may possibly be due to real differences of velocity between the spots concerned, but is more probably the result of diffusion of the spot image on the slit plate, inevitable in the long exposures required in St John's photographs, which were obtained with an autocollimating spectrograph of long focus. This would certainly diminish the apparent shift of the lines.

The relation between the intensity of the lines and the velocity of the radial motion, given in St. John's "Iron scale," is satisfactorily confirmed by my results, as will be seen by dividing my figures by the constant 1·36. The agreement is then very close, although my results are derived from a very limited region of spectrum and small number of lines of each intensity. The correspondence is indeed closer than might have been anticipated, considering the large individual variations, accidental or otherwise, shown in tables I, II and III.

Lines of intensity less than 1 cannot be measured with any approach to accuracy in my plates, excepting in a few cases, where lines of intensity 0 have been included with those of intensity 1.

Among the lines I have measured there are seven enhanced lines of iron. The individual radial motions given by these may be compared in tables II, III and VI with the mean radial motions given by other lines of the same intensity. The lines and their intensities are given below, with a reference to the tables in which they may be found, viz.—

Enhanced Fe lines.	Intensity.	Table.
4508·455	4	III and VI.
4515·508	3	III and VI.
4520·397	3	III and VI.
4522·802	2	VI.
4556·063	3	III and VI.
4584·018	4	III and VI.
4629·521	6	IIa and IIc.

[1] Monthly Notices of the Royal Astronomical Society LXX 223.

According to St. John's measures, "the enhanced lines show smaller radial displacements than the unenhanced lines of the same solar intensities, and would appear to originate at higher levels in and near sunspots."[1] I can find no evidence of any such systematic difference for the above enhanced Fe lines, compared with ordinary Fe lines of the same intensities. These particular lines were, however, not measured by St. John, who appears to have based his conclusions mainly on titanium lines.

In the plates of April 7, in which very large velocities are obtained in the western penumbra, some lines of nickel, chromium, and titanium were also measured, in addition to the Fe lines. Five lines of Ni, eleven lines of Cr and twelve lines of Ti give results which are not sensibly different from the lines of corresponding intensities in the Fe spectrum. In the case of Ti, five lines of intensity 2 give slightly greater mean displacements than the Fe lines of this intensity, and four lines of intensity 3 give displacements almost identical with the Fe lines of intensity 3 in the same region. This is not in agreement with St. John's results, according to which the Ti lines give sensibly smaller displacements than the Fe lines of the same intensity. Although the displacements in these spectra are large, amounting to about 0·035 A for intensity 2, these results can have but small weight compared with St. John's, which are based on a large number of measures.

Spectrum of Companion Spot.—It is of interest to compare the spectrum of the principal spot, which I will call spot A, with that of a companion spot closely following it, which I will call spot B (see plate III). This developed during the passage of the group across the disc, and on the dates April 6, 7, 8 and 9 spectra of both A and B were obtained. On the 8th, a radial slit passed through both spots, and both are recorded in one wide spectral image. The general appearance of the spectrum of spot B is more normal than that of spot A, for the displacements in the east and west penumbræ are more nearly equal, and there is no displacement observable beyond the limits of the penumbræ on either side. Measures of the displacements show however that, like spot A, the west or limb side yields higher velocities than the east, although the penumbra on the west is narrower than on the east. Details of the measures of the best image obtained on April 7 are given in table VI.

TABLE VI.

Date—1915, April 7.
Latitude of Spot + 16° (on central meridian).
Central distance (sun's radius = 1) 0·496 west.
Slit radial.

λ	Intensity.	East penumbra km/sec.	West penumbra km/sec.	λ	Intensity.	East penumbra km/sec.	West penumbra km/sec.
4505·003	1	− 0·99	+ 1·10	4515·508	3	− 0·89	+ 1·19
4529·849	1	− 0·68	+ 1·32	4517·702	3	− 0·79	+ 1·63
4542·600	1	− 1·16	+ 0·97	4520·397	3	− 0·89	+ 0·94
4565·002	0	− 1·09	+ 1·57	4548·024	3	− 0·87	+ 1·30
4566·693	1	− 1·14	+ 1·28	4556·063	3	− 0·96	+ 1·29
4567·046	1	− 1·52	+ 1·56	Means for intensity 3.	...	− 0·88	+ 1·27
4574·396	1	− 0·86	+ 1·80	4489·911	4	− 1·00	+ 0·96
4584·900	1	− 0·94	+ 1·40	4508·455	4	− 0·59	+ 1·24
Means for intensity 0 and 1.	...	− 1·05	+ 1·37	4584·018	4	− 0·33	+ 0·66
4490·942	2	− 1·10	+ 1·30	Means for intensity 4	...	− 0·64	+ 0·95
4522·802	2	− 0·63	+ 1·17	4494·738	6	− 1·20	+ 0·85
4531·801	2	− 0·97	+ 1·02	4525·314	5	− 0·44	+ 1·13
4560·266	2	− 0·96	+ 1·53	4531·327	5	− 0·83	+ 0·93
4574·899	2	− 1·00	+ 1·04	Means for intensity 5 and 6.		− 0·82	+ 0·97
Means for intensity 2.	...	− 0·93	+ 1·21				

[1] Radial Motion in Sunspots, II. Astrophysical Journal XXXVII.

Reduced to horizontal movement, the mean velocities are—

Line intensity.	East Penumbra km/sec.	West Penumbra km/sec.	Mean of E. and W. km/sec.
0 and 1	− 2·12	+ 2·77	2·44
2	− 1·87	+ 2·44	2·15
3	− 1·78	+ 2·56	2·17
4	− 1·29	+ 1·92	1·60
5 and 6	− 1·65	+ 1·96	1·80

The mean horizontal velocities given in the last column in the last part of the table appear rather larger than in spot A (table V), especially for the lines of intensity 5 and 6, which give slightly larger displacements than lines of intensity 4. It has been mentioned that in the case of spot A a diffusive widening of the lines occurs near the limits of the penumbræ, a diffusion in the direction of displacement only. This is also well seen in some images of spot B. If this is interpreted as a motion effect, it means that near the outer limits of the penumbræ some portions of the absorbing gases develop greater velocities than other portions. The phenomenon is of course involved in the Zeemann widening of the lines, and it tends to make estimates of the displacements uncertain, owing to a want of symmetry. It is for this reason possible that some of my measures of velocity, both in spot A and spot B, are over-estimates in the case of some of the stronger lines. It is possible that the more diffused portion of the strong lines is shown up in stronger contrast than in the case of the weaker lines.

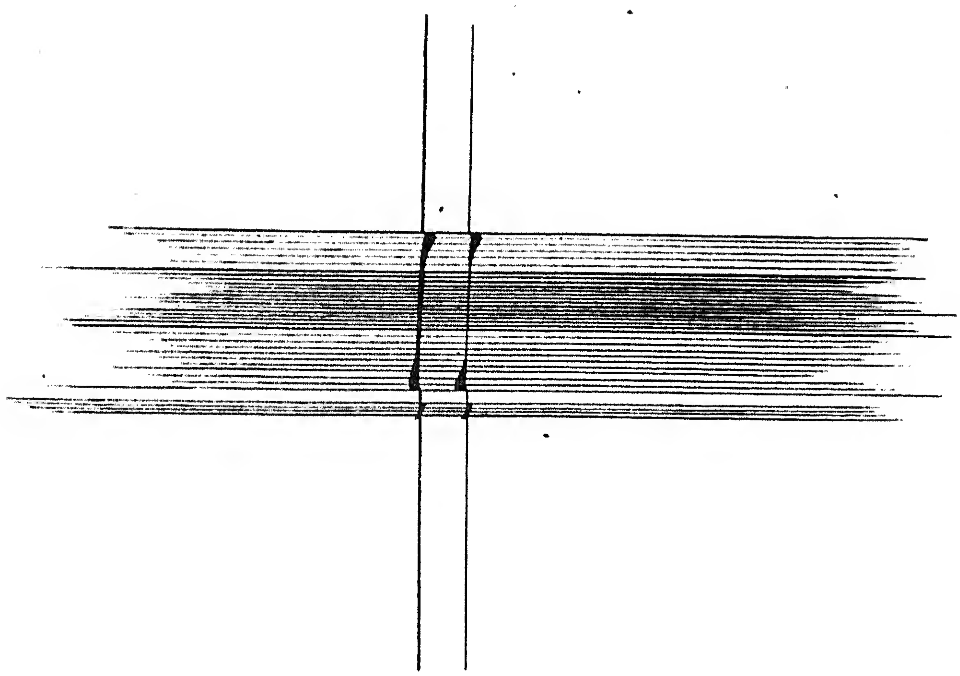

Fig. 2. Diffusive widening of lines near outer edges of penumbræ.

This diffusion of the lines in the direction of displacement does not seem to occur in all spots. In these spectra it is found near the outer limits of the penumbræ, a region where the lines are also intensified, so that in observing the spectrum visually one sees little black dots or lumps along the edges of the

penumbræ marking the most displaced portion of the lines, and sharply contrasting with the undisplaced lines outside the penumbræ. This appearance had been observed several times when focussing spot spectra before I had succeeded in photographing it. Fig. 2 is an exaggerated representation of this effect.

Spot B had a double nucleus. On the 6th and 7th of April a rift or bridge, roughly north and south, divided the umbra into an eastern and a western portion, and it is of interest to note that some of the lines of small intensity, notably the chromium line 4571·849, intensity 1, show a slight kink in this rift, indicating that each nucleus was forming an independent centre of radial movement with opposing currents in the rift, tending perhaps to separate the umbræ. At the outer limits of the penumbræ, and especially on the western side, where the displacement is greatest, the kink in the lines indicates a sudden drop in velocity from the maximum value of nearly 3 km/sec. to zero. One cannot say that any trace of the motion shift can be seen beyond the limit of the penumbra. Spot B differs markedly therefore from spot A in this respect, but larger scale photographs and still better definition might of course show a progressive decrease of velocity. I think I am justified in saying, however, that in spot B any progressive decrease of velocity must have been confined to an extremely narrow zone, perhaps not exceeding one-hundredth part of the diameter of the spot.

From the foregoing results, the following brief summary may be made :—

(1) The radial motion displacement may be very unequal at equal distances from the umbra of a spot, and the two spots investigated showed larger displacements on the limb side than on the centre side.

(2) Detached penumbræ appear to show no radial movement, except when secondary nuclei are developed in them, forming independent centres of radial motion.

(3) The radial movement may be continued for a considerable distance outside the limits of the penumbræ, or it may stop short at those limits.

(4) There is usually an acceleration of velocity from the umbra to the outer limits of the penumbra, and then a sudden fall to zero, or to a lesser speed which diminishes to zero at some distance outside the spot.

(5) The radial movement may amount to 4 km/sec. at one edge of the penumbra for lines of intensity 0 and 1 in large spots. The mean radial movement for east and west edges appears to be fairly constant for spots of the same diameter.

(6) There is a tendency to diffusion of the lines in the direction of displacement near the outer limits of the penumbræ in some spots, indicating turbulent motion.

(7) The relation found between line intensity and radial movement for Fe lines agrees with that given by St. John in his "iron scale."

(8) Enhanced lines of iron, and the lines of chromium, nickel, and titanium, in the region of spectrum investigated, do not show any systematic differences compared with ordinary iron lines having the same intensities.

MOVEMENTS AT RIGHT ANGLES TO THE RADIAL MOVEMENT.

The spectra photographed with a tangent slit were measured in the same way as the others. The displacement of the lines is of course very much smaller than with the radial slit, but is still quite obvious in some of the spectra. Interpreting the displacement as a motion parallel to the surface of the sun, the measures show velocities of about 0·5 km/sec. The first plate of the series, representing spot A on April 1, has three images of the spectrum impressed on it, by two slightly different but parallel sections through the umbra. All show a slight displacement to red at the outer limit of the south penumbra, but no appreciable displacement in the north penumbra. The spectrum representing the more westerly section gives a larger displacement than the others. This section passes through a wedge-shaped indentation in the umbra and through an apparently much disturbed region in the penumbra outside it, the displacement at the outer edge of the penumbra is equivalent to 0·6 km/sec. horizontal movement. The measurement in this spectrum of thirteen Fe lines of mean intensity 1·8 is given in table VII.

TABLE VII.

Date—April 1, 1915.
Latitude of Spot + 20°·7 (on central meridian).
Central distance (sun's radius = 1) 0·825 east.
Slit tangent.

λ	Intensity.	North Penumbra km/sec.	South Penumbra km/sec.
5273·339	3	− 0·32	+ 0·42
5273·558	2	0·00	+ 0·50
5288·705	2	+ 0·01	+ 0·27
5292·762	0	+ 0·44	+ 0·69
5294·134	0	+ 0·13	+ 0·88
5295·485	0	+ 0·30	+ 0·25
5307·541	3	− 0·06	+ 0·41
5315·252	1	+ 0·15	+ 0·48
5321·293	2	− 0·02	+ 0·61
5322·227	3	− 0·08	− 0·39
5326·331	1	+ 0·10	+ 1·05
5330·179	2	+ 0·13	+ 0·58
5333·089	4	+ 0·04	+ 0·42
Means	...	+ 0·06	+ 0·53

Reduced to horizontal movement, the velocities are—

North Penumbra.	South Penumbra.
+0·07 km/sec.	+ 0·64 km/sec.

This is the only plate obtained in the green region of the spectrum ; and although the exposures were of thirty seconds' duration, the spectra are under-exposed. A " Royal Standard Ortho " plate was used, and a solution of flavasine to cut out the fourth order violet. The definition of the penumbræ is good. On the same day, two hours later, two more spectra with a tangent slit were obtained : these include the region 4686 to 4785. The definition of the penumbræ is not so good as in the earlier plates, as the quality of the seeing at 10 a.m. is always inferior to that at 8 a.m. These spectra represent a section slightly to the east of the centre of the spot, and not passing through the wedge-shaped indentation. In both spectra there is a very slight shift to red over the whole spot, including probably the umbra itself, although the lines are here under-exposed and difficult to measure.

It would seem that the displacement first observed at the southern limit of the south penumbra in all spectra photographed at 8 a.m. had spread over the entire spot at 10 a.m. It cannot represent a rotational movement in the spot, since both sides are moving in the same direction. The displacement is of course relative to the photosphere a short distance outside the spot, and may be interpreted in different ways : there may be currents outside the spot, moving in a westerly direction, or the spot as a whole may be drifting eastwards, or the movement may be normal to the surface, and indicate a general descent of the gases over the spot, or finally there may be a combination of these movements. If the movement is parallel to the sun's surface, it amounts to 0·46 km/sec ; but if it is normal to the surface, it indicates a descending movement amounting to 0·65 km/sec. The mean velocities in the line of sight from fourteen Fe lines of average intensity 3·1 are as follows :—

	North Penumbra.	South Penumbra.
Observed velocities	+ 0·37 km/sec.	+ 0·39 km/sec.
Reduced to horizontal movement	+ 0·45 km/sec.	+ 0·47 km/sec.

On the next day, with the spot at 0·711 east from the centre, the displacement is all in the north penumbra, and is still towards red. As the spot was then about 45° from the centre of the disc, the deduced velocities

parallel to or normal to the surface are the same, and amount to as much as 0·9 km/sec. The mean velocities from twelve Fe lines of average intensity 3·0 are as follows :—

	North Penumbra.	South Penumbra.
Observed velocities	+ 0·65 km/sec.	− 0·07 km/sec.
Reduced to horizontal movement	+ 0·91 km/sec.	− 0·10 km/sec.

The tangent slit spectra of spot A obtained near the eastern limb indicate therefore considerable movements of recession of an irregular character, and little or no movement of approach. They give no evidence of rotation of the gases at the level of the reversing layer, and it is not possible to say whether the movements are parallel to or normal to the solar surface.

After the meridian passage, and when the spot was nearing the western limb on April 9, tangent spectra yield a different result. The lantern plate spectra were not measured, as they give poor definition of the penumbræ, but a Wratten "Instantaneous" plate exposed for ¼ second in the region 4450 gives a distinct image of the spot, and in this there is evidence which may be interpreted as a rotation of gases over the spot, since opposite sides of the spot give opposite movements. There is a very distinct displacement to violet at about the middle of the south penumbra, the lines over the outer portion being undisplaced. There was a small satellite spot on the south edge of the penumbra, and the point where the displacement ceases appears to be the junction between the penumbra of the satellite spot and the main penumbra. On the north side, the displacement towards red is distinct, but less in amount than the violet shift on the south side. The other tangent slit spectra taken on this date show the same displacements, but less distinctly.

The measures of thirteen Fe lines of mean intensity 1·7 give the following results :—

	North Penumbra	South Penumbra.
Observed velocities	+ 0·56 km/sec.	− 0·76 km/sec.
Reduced to horizontal movement	+ 0·65 km/sec.	− 0·88 km/sec.

The spot diameter measured from the points of greatest shift was 41,000 km. Assuming a continuous rotation movement, at a mean speed of 0·77 km/sec, at the outer edge, the entire spot would complete a rotation in about 46 hours, the north penumbra moving towards west, that is a clockwise rotation. This is not the direction found by Prof. Hale from the magnetic polarity of spots. He states that "in bi-polar groups of low latitude, the preceding spot-vortices rotate counter-clockwise in the northern hemisphere."[1] The spot was the preceding member of the group, approximately in latitude + 21°.

It is very doubtful whether these line displacements really indicate rotation of the gases over the spot. There is no evidence of rotation in the shape of the spot itself and its outlying satellites, as shown in our photoheliograph plates. The umbra of the preceding spot is of rather irregular form on April 6 and 7 (see plate III, figs. 1 and 2), but it assumes an elliptical shape with less marked irregularities as the west limb is approached. This is mainly due to foreshortening, the long axis of the ellipse being parallel to the limb. There is, however, a wide indentation on the north-east side of the umbra which occupies the same position on the dates April 6, 7, 8 and 9. The penumbra is greatly extended on the north side of the spot, as well as to the south-east ; but throughout the interval of four days there is no change in the position angle of these outlying parts of the spot. If the gases of the reversing layer above the spot share in the rotational movement of the underlying spot vortex, one would expect to find evidence of rotation in the markings of the spot itself, which should turn half round in a day, from the evidence of the line-shifts. But the spot-markings do not show this rotation, although the *radial* movement of the overlying vapours is most distinctly indicated in the radial structure of the penumbral filaments.

From the whole of the evidence so far obtained with the tangent slit, I conclude that irregular movements at right angles to the radial movement may occur in the penumbræ of spots, and that if a rotation movement exists in some spots, it is not a constant and regular feature, as is the radial movement.

THE OBSERVATORY, KASHMIR,
27th June 1916.

J. EVERSHED,
Director, Kodaikanal and Madras Observatories.

[1] Annual Report of Mount Wilson Solar Observatory for 1915.

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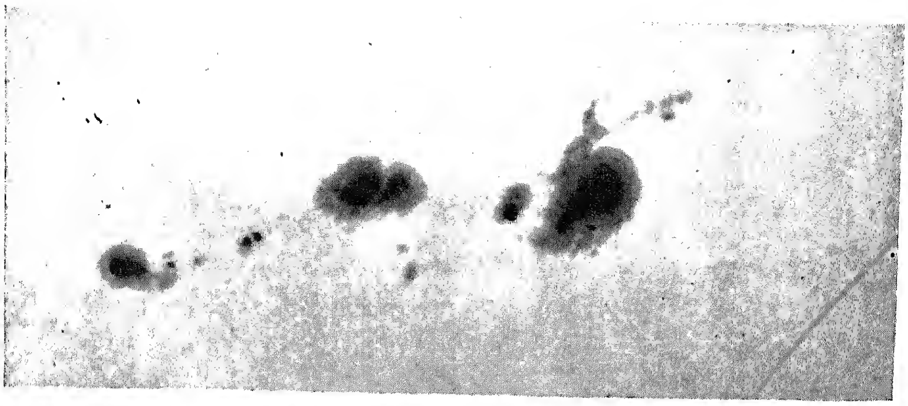


Fig. 1.

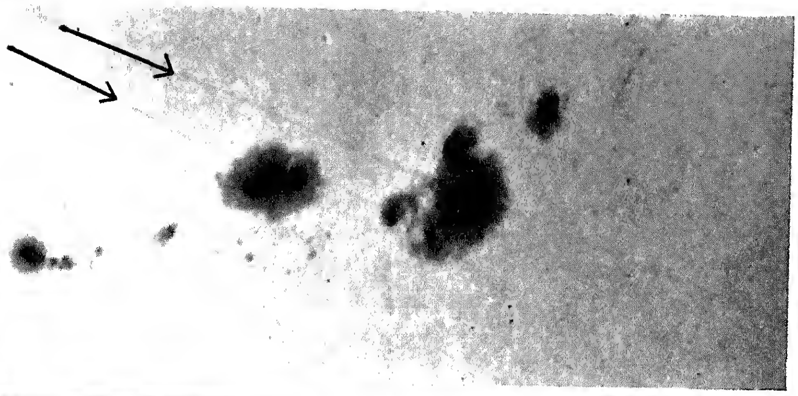


Fig. 2.

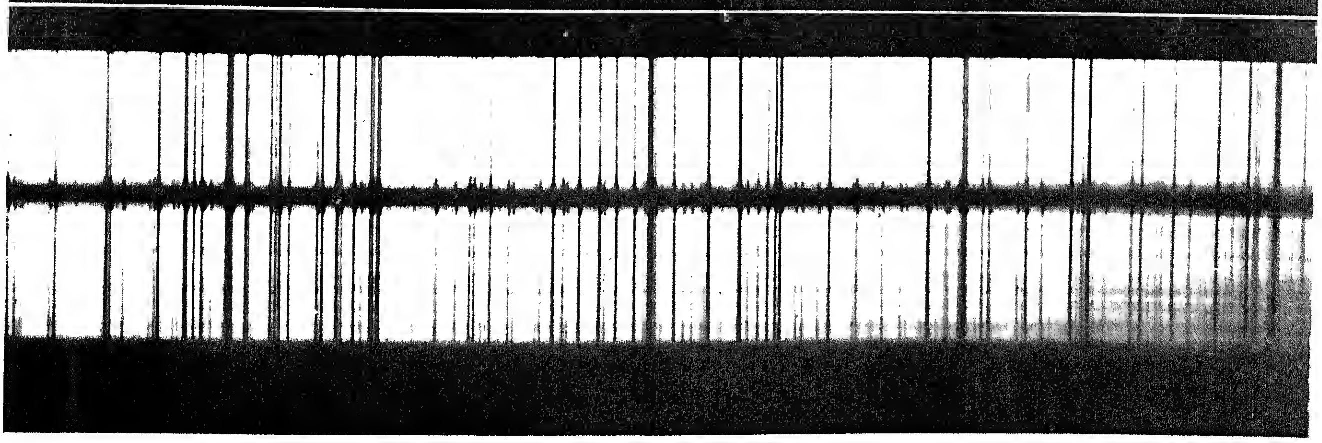


Fig. 1. Spot group 1915, April 6th, 7^h. 57^m. I. S. T.
„ 2. „ „ „ April 7th, 8^h. 02^m. I. S. T.
„ 3. Spectrum of following spot } April 7th, Region 4520—4580. Slit radial.
„ 4. „ „ preceding spot }
The arrow marks in Fig. 2 indicate the direction of the radial slit in Figs. 3 and 4.

Kodaikanal Observatory.

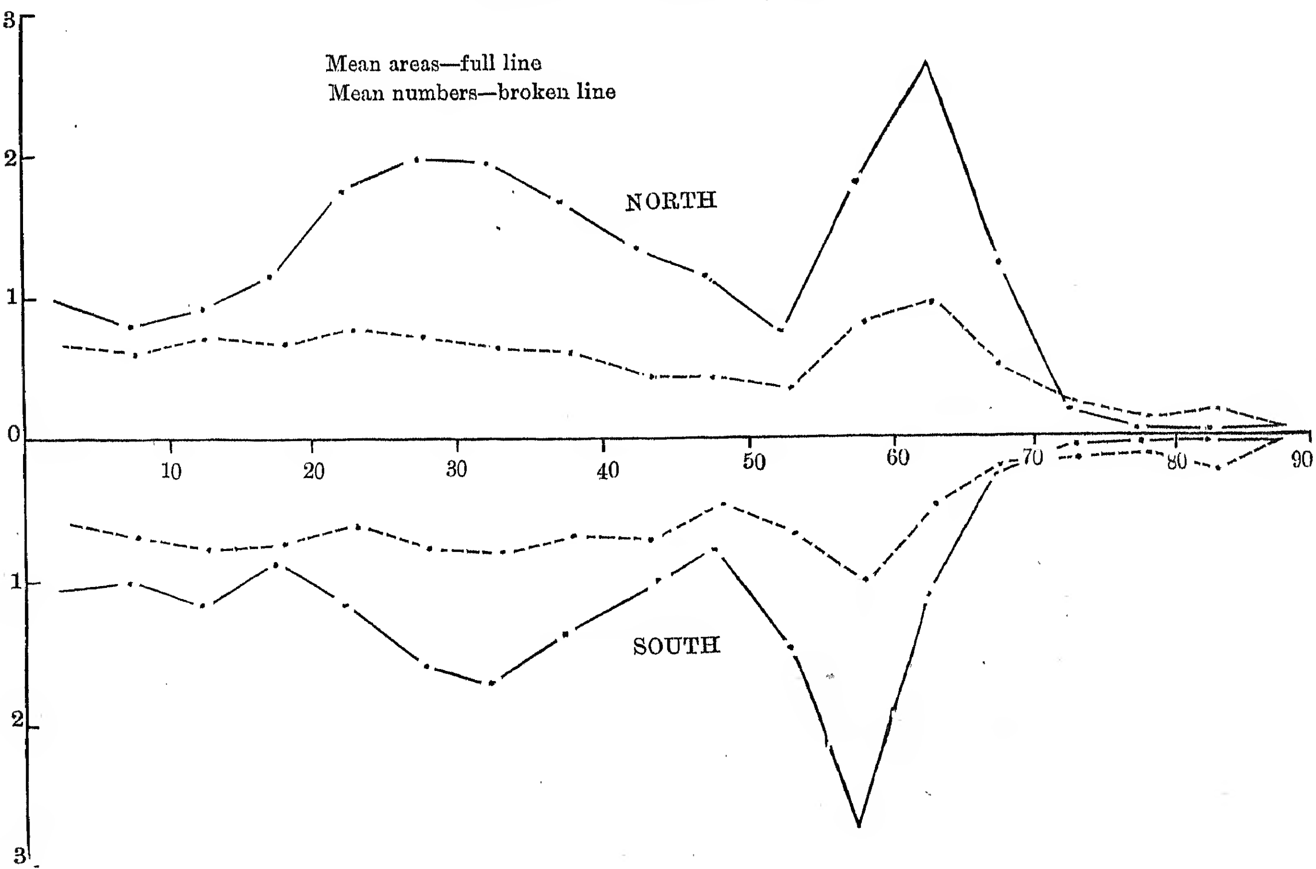
BULLETIN No. LII.

SUMMARY OF PROMINENCE OBSERVATIONS FOR THE FIRST HALF OF THE YEAR 1916.

In this bulletin, the prominence observations made at Srinagar by the Kashmir expedition under Mr. J. Evershed, the Director, have been used to supplement those made at Kodaikanal. At Kodaikanal the visual observations were practically confined to displacements of the hydrogen lines and to metallic prominences, as the position angles, heights, and areas can now be much more satisfactorily determined from the photographs. For those days when Kodaikanal photographs of prominences were incomplete, imperfect or wanting, the observations made at Srinagar were substituted when available. Visual observations were made at Srinagar until February 28, none of which were required, but eleven prominence photographs taken at Srinagar were used to supplement the Kodaikanal series. Observations were obtained on 171 days, counted as 166 effective days.

The distribution of prominences observed and photographed during the half-year ending June 30, 1916, is represented in the accompanying diagram. The full line gives the mean daily areas and the broken line the mean daily numbers for each zone of 5° of latitude. The ordinates represent tenths of a square minute of arc for the full line and numbers for the broken line.

FIG. 1.—MEAN AREAS AND MEAN NUMBERS OF PROMINENCES, KODAIKANAL AND SRINAGAR. JANUARY 1 TO JUNE 30, 1916.



The distribution, which is practically unaffected by the inclusion of the Srinagar observations, is very similar to that in the previous half year, except that the maximum of the belt between 50° and 70° has shifted 5° towards the poles.

The mean daily areas and daily numbers (corrected for partial observations) are given in the table below, where the data for Kodaikanal observations alone are also given separately for the sake of uniformity with previous bulletins. It is seen that the inclusion of Srinagar observations hardly affects the results.

		Mean daily areas (square minutes).	Mean daily numbers.
Kodaikanal and Srinagar observations (166 effective days).	North	2·06	9·51
	South	1·77	9·77
	Total ...	3·83	19·28
Kodaikanal observations (158½ effective days).	North	2·08	9·68
	South	1·80	9·97
	Total ...	3·88	19·65

Compared with the previous six months there is a decrease of 22·6 per cent in areas and an increase of 26·1 per cent in numbers, the average area of a prominence having decreased from 0·324 square minutes in the last half of 1915 to 0·199 square minutes in the first half of 1916.

The monthly, quarterly, and half-yearly frequencies and the mean heights and extents of the prominences observed at Kodaikanal are given below in the following table. The frequencies are derived from the number of effective days.

Abstract for the first half of 1916 (*Kodaikanal*).

Month.	Number of days of observation. Total.	Effective.	Number of prominences.	Mean daily frequency.	Mean height.	Mean extent.
1916.					″	°
January	31	31	637	20·5	40·0	3·03
February	27	27	529	19·6	34·8	3·16
March	30	30	661	22·0	35·7	2·65
April	29	26½	533	20·1	35·6	3·11
May	29	28	488	17·4	37·5	2·78
June	20	16	267	16·7	34·2	2·76
First quarter ...	88	88	1827	20·8	36·9	2·93
Second quarter ...	78	70½	1288	18·3	36·0	3·69
First half-year ...	166	158½	3115	19·7	36·5	3·25

...ere is a decrease in both the mean height and the mean extent which accounts for the decrease in the ... prominence noted above.

Although the mean height has decreased slightly, an eruptive prominence of unprecedented height was photographed at Kodaikanal and Srinagar on May 26. The prominence had attained its greatest development at 8^h 57^m I.S.T. when it resembled an enormous fountain 7′ in height. At 9^h 3^m rapid dissolution was

taking place, and the highest portion was found to be moving with high velocity away from the sun. The last remnants were photographed at $9^h\ 22^m$ at the enormous height of $18'$ above the limb. A full description of this prominence will be published separately.

Distribution east and west of the sun's axis.

In the observations at Kodaikanal and Srinagar combined, areas show a preponderance at the eastern limb and numbers, a slight preponderance at the western limb.

1916 January to June.	East.	West.	Percentage east.
Numbers observed	1595	1605	49·84
Total areas in square minutes	3380	2983	53·12

Metallic prominences.

The following metallic prominences were recorded in the half-year. The two prominences printed in italics were recorded at Srinagar :—

TABLE I.—METALLIC PROMINENCES—JANUARY TO JUNE 1916.

Date.		Hour I.S.T.		Base.	Latitude. North.	Latitude. South.	Limb.	Height.	Lines.
1916.		H.	M.	°	°	°		"	
January	4	8	45	6		12	E	30	D_1, D_2, b_1, b_2, b_3, b_4.
	6	8	56	9	21·5		E	60	b_1, b_2, b_4 slightly bright.
	7	9	5	5	25·5		E	50	D_1, D_2, b_1, b_2, b_3, b_4 over the whole height at +23° and +26° and over 25″ at other places.
	7	8	55		22		W	35	D_1, D_2, b_1, b_2, b_3, b_4.
	8	9	5		21		W	30	6677, D_1, D_2, 5316·8, 5284·2, 5276·2, b_1, b_2, b_3, b_4, 5018·6, 5016, 4924·1.
	13	8	33			17	W	10	4924·1, 5016, b_1, b_2, b_3, b_4, 5234·8, 5276·2, 5284·2, 5316·8, 5325·8, 5337·0, 5363·0, D_1, D_2.
	18	*10*	*25*	*2*		*19*	*W*	*25*	*Whole prominence visible in* D_1, D_2, b_1, b_2.
	21	8	50	4	39		E	65	D_1, D_2, b_1, b_2, b_3, b_4.
	22	8	37		22		E	15	D_1, D_2, b_1, b_2, b_3, b_4.
	23	8	45			20	E	60	D_1, D_2, b_1, b_2, b_3, b_4.
	24	*13*	*0*		*23·5*		*W*	*20*	*6677*, D_1, D_2, b_1, b_2, b_3, b_4.
	25	8	50	2		42	W	60	D_1, D_2, b_1, b_2, b_3, b_4 5316·8.
	25	8	59	2	24		W	35	D_1, D_2, b_1, b_2, b_3, b_4, 5316·8.
February	5	8	54	3		20·5	W	45	4924·1, 5016, b_1, b_2, b_3, b_4, 5197·8, 5234·8, 5276·2, 5316·8, 5361·8, D_1, D_2, 6677 (the last line only slightly bright).
	13	8	45	1		18·5	W	90	} 6677, D_1, D_2, b_1, b_2, b_3, b_4, 5316·8, 4924·1.
	13	8	45	1		15	W	30	
	18	8	26	5		66·5	W		No prominence. D_1, D_2, b_1, b_2, b_3, b_4, 5316·8 bright over 5°; metallic at $8^h\ 56^m$ also but not at $9^h\ 20^m$.
	24	8	49	1		11·5	E	25	b_1, b_2, b_4.
	26	9	0	3		19	W	55	D_1, D_2, b_1, b_2, b_3, b_4, 4924·1, 5016, 5018·6, 5276·2, 5284·2, 5316·8, 5404·4, 6677.
March	14	8	36			16	W	70	D_1, D_2, b_1, b, b_3, b_4, 4924·1, 5016, 5018·6, 5316·8, 6677.
	14	8	20	2	20		W	25	D_1, D_2, b_1, b_2, b_3, b_4, 4924·1, 5016, 5018·6, 5316·8, 6677.
	17	9	0	7	15·5		W	55	D_1, D_2, b_1, b_2, b_3, b_4, 5316·8.
	23	9	0			28	E	15	4924·1, 5016, 5018·6, b_1, b_2, b_3, b_4, 5316·8, D_1, D_2.
	28	8	44	4	22		E	15	D_1, D_2, b_1, b_2, b_3, b_4, 5316·8. 6677.
	31	8	38	2	15		E	40	4924·1, 5016, 5018·6, b_1, b_2, b_3, b_4, 5197·4, 5234·8, 5276·2, 5284·2, 5316·8, 5363·0, 5425·5, 5535·0, D_1, D_2, 6677, 7065.

Date.		Hour I.S.T.		Base.	Latitude.		Limb.	Height.	Lines.
					North.	South.			
1916.		H.	M.	°	°	°		″	
April	1	9	20	4	13		W	25	D_1, D_2, b_1, b_2, b_3, b_4, 6677. Prominence well visible in b_1, b_2, b_3, b_4.
	3	8	56		19		E	30	D_1, D_2, b_1, b_2, b_3, b_4, 6677 at base only.
	6	8	37	10		31	W	50	D_1, D_2, b_1, b_2, b_3, b_4, 5316·8, 4924·1, 5018·6, 5197·8, 5234·8, 5276·2, 6677.
	26	8	40		11		E	35	D_1, D_2, b_1, b_2, b_3, b_4.
	29	8	36	4	12		E	130	4924·1, 5018·6, b_1, b_2, b_3, b_4, 5197·8, 5234·8, 5276·2, 5316·8, D_1, D_2.
May	6	8	35	1		20·5	E	15	4924·1, b_1, b_2, b_3, b_4, 5197·8, 5234·8, 5276·2, 5284·8, 5316·8, 5363·0, D_1, D_2, 6677.
	16	8	43	5		25·5	E	25	D_1, D_2, b_1, b_2, b_3, b_4, 6677.
June	7	8	34	4	11		W	30	b_1, b_2, b_3, b_4.

There is an increase on the previous half-year in the number of metallic prominences observed.

Displacements of the hydrogen lines.

The displacements observed at Kodaikanal are given in Table II. A and those observed at Srinagar up to February 28 in Table II. B.

TABLE II. A.—DISPLACEMENTS OF THE C LINE IN PROMINENCES OBSERVED AT KODAIKANAL, JANUARY TO JUNE 1916.

Date.		Hour I.S.T.		Latitude.		Limb.	Displacement.			Remarks.
				N.	S.		Red.	Violet.	Both ways.	
1916.		H.	M.	°	°		Å	Å	Å	
January	1	8	55	63·5		E		Slight		At north end.
	2	8	48		19	E		Slight		
	3	8	49		49	W	Slight			
		8	45	61		W	Slight			At top.
	4	8	45		12	E		Slight		
		8	45		9	E		0·5		
	5	8	48	11		E	Slight	Slight		To red at base; to violet at top.
	6	8	48		86	W	Slight			
	7	9	10	18		E		Slight		
		9	0		58·5	W	Slight			Over lower portion.
		8	55	22		W	2			Over upper half.
	8	9	5	21		W	1	1		
	9	8	54		53	W	Slight			At south end.
		8	48	22		W		0·5		Over jets.
	12	8	42		39	E		0·5		
		8	40		69·5	E		0·5		
		8	50		34	W	Slight			
	13	8	55		35	E		2		
		9	0		44·5	W	Slight			At base.
		8	29	26		W	0·5			
		8	22	83·5		W	Slight			
	15	8	49	62·5		E		1		At top.

Date.		Hour I.S.T.		Latitude.		Limb.	Amount of displacement.			Remarks.
				N.	S.		Red.	Violet.	Both ways.	
1916.		H.	M.	°	°		Å	Å	Å	
January	15	8	54		31	E	2			
		8	39	63		W	Slight			At base.
	16	8	56		8	W	Do.			
	17	8	48	85		E	1·5			At top; not seen at $9^h 5^m$.
	19	8	42	23		E	1·5			
		8	32		55	E		0·5		} At base.
		8	32		65	E		Slight		
		8	30		77	E		Do.		
		8	48	10		W		1		Over lower part.
	21	8	56	6·5		E	Slight			
	22	8	35	36		E		0·5		
		8	35	42		E	1	Slight		To red at top; to violet at base.
	23	8	49		30	E	Slight			
	25	8	59	24		W	1	2		To red at top; to violet at base.
	27	9	5		23	W	Slight	1		
	28	9	10		24	W	Do.			At base.
	29	9	0	71		E	0·5	1·5		To red at base; to violet at top. No displacement at $9^h 2^m$.
		8	37		55·5	W			Slight	Symmetrically widened.
		8	36		44·5	W		Slight		
		8	50	17		W	Slight			
		8	51	32		W	1			
		8	56	66·5		W		1		
	30	8	32	79		E			Slight	
		8	27	71		E	Slight			
		8	47		82	W			Slight	To red only for 0·5 Å at $8^h 49^m$.
		8	51		79	W		Slight		At top.
		8	44		34	W		0·5		At base.
		8	37		3	W	Slight			
February	1	9	55	51·5		E	2			
		9	50	15·5		W		Slight		At top.
	3	8	55	26		E	Slight	Do.		The violet displacement a little to the north of the other.
		9	2		55·5	W	Slight			At base; not seen at $9^h 6^m$.
		8	22		0·5	W	0·5			At top.
	4	9	40		17	W	1			
	5	8	43	62		E		0·5		At top.
		9	16	34·5		E	0·5			
		9	20		37	E	2			
		8	54		20·5	W	0·5	Slight		To red at top; to violet at base.
		9	9		14·5	W		2		
		8	49		5	W	Slight			
		8	47	59		W			Slight	
	6	8	54	25		E			Do.	
		8	50		9	E	Slight	Slight		To red at base; to violet at top.
		9	0	20		W		Slight		
	8	8	55	25·5		W	Slight	Do.		To red at top; to violet at base.
		8	53	63·5		W		Slight		
	10	8	55	12·5		E	0·5			Two bright points on chromosphere.
		8	46		82	E	Slight			
		8	45		66	W	Do.			
	12	8	43		28	E	0·5			At base. 4 Å to violet and 1 Å to red at $8^h 47^m$. No displacement a $8^h 55^m$.
	13	8	45		15	W		3		
		8	45		19	W		0·5		3 Å to violet at top at $9^h 12^m$.
		8	39	59		W	Slight			
	14	8	47		82·5	W		Slight		
		8	31	43		W			Slight	

Date.		Hour I.S.T.		Latitude.		Limb.	Amount of displacement.			Remarks.
				N.	S.		Red.	Violet.	Both ways.	
1916.		H.	M.	°	°		Å	Å	Å	
February	17	8	55	12		W	Slight	1		To red at base ; to violet at top.
	18	8	31		82·5	E	Do.			
		8	28		55	W	Do.			At base.
		9	8	48·5		W	Do.			
	20	8	24	63		W	Do.			
	22	8	25		67	E		Slight		
		8	48	10		W		1		
	24	8	49		11·5	E	Slight			
		9	4		68	E	Do.			
		8	35		8	W		Slight		Over lower half.
	25	8	24	27		E		2		Over chromosphere.
		8	37		20	E	1·5			At base.
		8	58		15	W		1		
	26	8	53	62		E			Slight	
		8	45		20	E	Slight			
		9	14		18	W	Do.	1		
	27	8	44		58	E	Do.			
		8	27		21	W		0·5		
		8	26		10	W		Slight		
	29	8	22	10·5		E		Do.		At top.
		8	17		15	E	Slight			
March	1	8	55		17	E	2	1·5		At two different points.
	2	8	49		22	E	Slight	Slight		To red at top ; to violet at base.
		8	56		62–76	E	Do.	1·5		Changing ; at 8^h 56^m whole prominence bodily displaced to violet for 1·5 Å at northern end and C slightly displaced to red at 74° E. Southern half of prominence displaced to violet for 1·5 Å at 9^h 15^m.
		8	36	34		W	Slight			At top.
	4	9	3	82·5		E		Slight		
		8	50	18		E	Slight	Do.		To red at base ; to violet at top.
		8	44		57·5	E	Do.			
	5	8	28	61		E		Slight		
		8	32	25–27		E		Do.		Over streamers.
		9	3	18		E		1		At top.
	6	9	0	70		W	0·5			
	8	8	28	20		E	2·5	2		In different places.
		8	30		70	E	Slight			
	9	8	35		57·5	E			Slight	
	10	8	35		67	E	Slight			
	12	8	27	82·5		E		Slight		
		8	20		24	W	Slight			
	13	8	45	28		E	1			Over chromosphere.
	14	8	36		16	W	Slight	Slight		At different points.
		8	20	20		W	0·5			At top.
		8	27	21		W	0·5	1		
	15	8	55		20·5	W	1	0·5		
	16	8	15		32	E	Slight			Over chromosphere.
		8	25		24	W	Do.			At top.
	17	8	30	15·5		W			2	To violet only for 1·5 Å at 9^h 0^m.
	20	8	55	42·5		E		2		
	21	8	39		62	W	Slight			At top.
	23	8	35	76·5		E	Do.	Slight		To red at top ; to violet at base.
		8	55	26		E	Slight			
		9	0		28	E			Slight	
	26	8	30		34·5	W		Slight		
	28	8	36	82		E		Do.		At top.
		8	44	22		E			Slight	
		8	46		10·5	E	Slight			
		8	48		19·5	E	Do.	Slight		To red at base ; to violet at top.

Date.		Hour I.S.T.	Latitude.		Limb.	Amount of displacement.			Remarks.
			N.	S.		Red.	Violet.	Both ways.	
1916.		H. M.	°	°		Å	Å	Å	
March	29	9 40	14		E		Slight		Over whole prominence.
		9 43		19·5	E	0·5	Do.		To red in the southern half; to violet in the northern.
		9 23		20	W	1			Over whole prominence.
	30	8 40	6		E	0·5			
	31	8 38	16		E		Slight		At north end.
		8 37	8		E		Do.		At top.
		8 32		59	E	Slight			At south end.
April	1	9 5	13		W	2·5	1	1	C bulged out 1 Å on the lower mass and displaced at 6 or 7 points on the upper part 2·5 Å to red and 1 Å to violet.
	3	8 56	26		E		Slight		At northern end of prominence.
		9 0	11		E	Slight			At base.
		9 14		72	E	Do.			
	4	8 35	62·5		E	1			
		9 5	19·5		E		Slight		
		9 14		72	W		Do.		
		8 45	28		W	Slight			
	6	8 50		81	W		Slight		
		8 37		31	W	Slight			At two or three points.
		8 33	21		W	Do.			
	7	9 32		15·5	E		Slight		Over whole prominence.
		9 40		53·5	W	4			
		9 20	29		W		Slight		
	10	8 53		15	W		1		
	11	8 29	6		E	1·5			
		8 48	35		W		1 to 5		Whole prominence displaced, amount ranging from 1 to 5 Å.
	18	8 53	29		E		Slight		
		8 53	23		E		Do.		
	22	8 32	82		E		Do.		
	23	9 2	65		E	Slight			At base.
		9 0	23		E		Slight		
	24	8 41	22		E		Do.		At top.
		8 43		25	E	Slight	0·5		
		8 49		84	E	Do.			
	25	8 33	59·5		E	Do.			At northern end.
		8 39		34	E	Do.			At top.
		8 35		75·5	E	Do.			
	26	8 40	11		E		1		
		8 32		66	E		0·5		At top.
	27	8 40	25		E		Slight		
		8 45		81	E		Do.		
	29	8 58	79		E		0·5		
		8 40	32		E	0·5			At base.
		8 36	12		E	Slight	Slight		To red at base; to violet at top.
		8 32		16	E	Slight			
		8 32		18	E		Slight		
	30	8 44	14		E	Slight			
May	2	8 30		17·5	E		1		At top.
		8 25		57	E	Slight			
	4	8 19	82		E		Slight		
		8 40		17	E	Slight	Do.		To red at base; to violet at top.
		8 21	57		W		Slight		
	6	8 31		28·5	E	Slight			At top.
	7	8 35		19·5	E	Do.			
		8 40		36	E		Slight		At top.
		8 26	29		W	Slight			At top.

Date.		Hour I.S.T.		Latitude.		Limb.	Amount of displacement.			Remarks.
				N.	S.		Red.	Violet.	Both ways.	
1916.		H.	M.	°	°		Å	Å	Å	
May	11	8	26		45	E			Slight	Symmetrically widened.
		8	42		17	W	Slight	Slight		The violet displacement a little to the north of the other.
	13	9	0		45	E	Slight			At base.
		8	49	8		W	Do.			
	14	8	41	69		E	Do.			
	15	8	40		17	W	Do.			
	16	8	23	80·5		E		Slight		
		8	37	17		E		Do.		
		8	43		25·5	E	0·5			Over the streamer at top.
	21	9	12		13·5	E		Slight		At top.
		9	12		12	E	Slight			
	22	9	52	37		E	1			
		10	19		17·5	E	1			
	23	9	34	22		E	Slight	Slight		To violet over lower and to red over upper part of prominence.
	24	8	23	56		W		Do.		
	25	8	39		23	W		Do.		
		8	35	15·5		W		0·5		
	26	8	23	64		E		Slight		An extraordinarily tall prominence over 15′ in height. At 8^h 50^m C was displaced 3 Å to red over lower half and slightly to violet over upper half.
	27	8	59	25		E	Slight			At northern end.
		8	58	19		E		Slight		Do.
		9	9		10	W	1	Do.		To red at top ; to violet at base.
	30	10	0		71	W	0·5			
	31	8	47	22·5		W	Slight			
		8	40	73·5		W		Slight		At base.
June	1	8	46		32 to 45	E	Slight	1·5		Slightly to violet at top over northern half and for 1·5 Å to violet over southern half ; slightly to red at base at southern end. At 8^h 52^m C was displaced 3 Å to violet over top of southern half.
		8	29		12	W	2			
		8	20	88·5		W		Slight		
	2	10	20		61·5	E		Do.		At top.
		9	27		12	W	3	1		Not seen at 9^h 29^m.
		9	29		14	W	Slight			
	7	8	34	11		W	Do.			At top.
	8	9	35		26	E	Do.			
		9	46	13·5		W		Slight		
	9	9	18		14·5	E			Slight	
	10	9	9	11·5		W		1		Over whole prominence.
	14	11	6		11·5	W			Slight	
	17	8	35		10·5	E	Slight			
	23	8	35	14·5		W		Slight		
	30	9	20		11	W	1			

TABLE II. B.—DISPLACEMENTS OF THE C LINE IN PROMINENCES OBSERVED AT SRINAGAR. 1ST JANUARY TO 28TH FEBRUARY 1916.

Date.		Hour. I.S.T.	Latitude.		Limb.	Amount of displacement.			Remarks.
			N.	S.		Red.	Violet.	Both ways.	
1916.		H. M.	°	°		Å	Å	Å	
January	2	9 45		7	E	1 to 3	1 to 3		Prominence 5°·5 broad. C displaced 1 to 3 Å to violet at the southern end and the same amount to red over the rest of the prominence. Displacement to violet same as before but only 0·5 Å to red at $9^h 52^m$. Displacements in both directions very slight at $10^h 45^m$.
	4	10 30		8	E		2		
	5	14 30	9·5		E	Slight			At base.
	7	16 10	71		W		0·5		
	8	12 20		20·5	W	Slight			
	8	12 24	31·5		W	Do.	Slight		Near base.
	10	11 2	70·5		E		Do.		At base.
	17	15 33	22		W		1		Near base at northern end.
	21	14 10		23·5	W		0·5		Over whole prominence.
	22	11 18	16		E	2			
	24	13 0	23·5		W			1	1 to 2 Å to red at $15^h 0^m$.
	25	11 15	28·5		W	0·5			
February	18	14 33	27·5		W		Slight		
	22	9 57		69	W		1		

There was a large increase on the previous half-year in the number of displacements observed at Kodaikanal. There were 127 in the northern hemisphere and 133 in the southern; there were 148 or 56·9 per cent in the eastern and 112 in the western. One hundred and fifteen were to the violet, 129 to the red and 16 both ways simultaneously. Between 0° and 30° of latitude there were displacements observed in 152 prominences, between 31° and 60° in 47, and between 61° and 90° in 61.

Reversals and Displacements of the C line on the Disc.

Three hundred and five reversals of the C line, 34 darkenings of the D_3 line, and 103 displacements were recorded. Each of these is an increase on the second half-year of 1915. Their distribution east and west of the central meridian is given below :—

		East.	West.
Kodaikanal.	Reversals of C near spots	161	144
	Darkenings of D_3	17	17
	Displacements of C	58	45

There was, as usual, a large preponderance of displacements towards the red, 70 being to the red, 25 to the violet, and 8 both ways simultaneously.

Prominences projected on the Disc as Absorption Markings.

The grating spectroheliograph for photographing the absorption markings in H_α light was in regular use during the six months. Photographs were obtained on 147 days, counted as 133 effective days. The

mean daily areas in millionths of the sun's visible hemisphere, corrected for foreshortening, and the mean daily numbers are given below :—

	1916 Jan.—June. Areas.	Numbers.
North	406·1	5·0
South	439·9	5·7
Total ...	846·0	10·7

The daily number is the same as for the previous six months, but there is again a diminution in areas. The distribution in latitude is given in the accompanying diagram. The diminution in the mean daily areas is seen to be largely due to the decrease in activity in the belt between 50° and 70°.

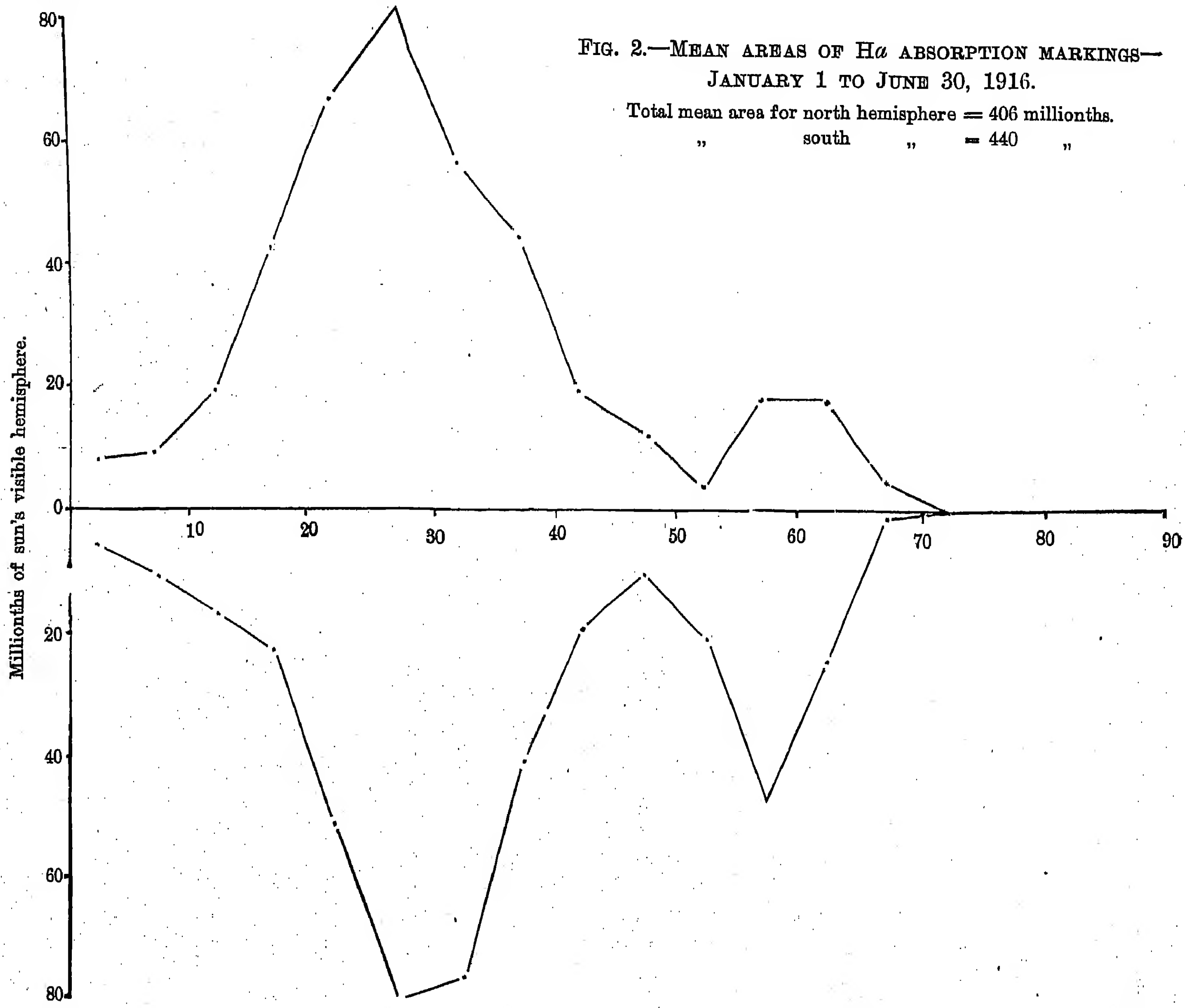


Fig. 2.—Mean areas of Hα absorption markings—January 1 to June 30, 1916.

Total mean area for north hemisphere = 406 millionths.
" south " = 440 "

Hitherto there has been a persistent excess of Hα markings on the eastern side of the central meridian, but for this half-year there is a defect in both areas and numbers; the percentage on the eastern side of the central meridian is 48·56 in areas and 48·77 in numbers.

The Observatory, Kodaikanal,
29th August 1916.

T. ROYDS,
Assistant Director.

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BULLETIN No. LIII.

THE DISPLACEMENTS OF NICKEL AND TITANIUM LINES IN THE SUN AND ARC.

BY T. ROYDS, D.SC.

The displacements of the iron lines in the solar spectrum have been given in previous bulletins [1], and from the sun-minus-arc displacements Mr. Evershed deduced a vertical current at the centre of the sun's disc decreasing with depth, and a low pressure in the sun. It was shown, however, that lines which are unsymmetrical in the arc have abnormal displacements in the sun, and these lines had to be left out of consideration. In extending the investigation to nickel and titanium it has to be remarked that these abnormal displacements are much more frequent than with iron. In the case of nickel it is doubtful whether there are any really symmetrical lines in its spectrum. So rare are symmetrical lines in nickel and titanium that it has not been possible to confirm, except to a limited extent, the conclusions arrived at from the iron lines, but one can only say that the results from nickel and titanium are not inconsistent with those indicated by iron.

Five separate investigations of displacements were carried out, namely :—

(i) Centre of sun's disc minus centre of nickel arc,
(ii) Centre of sun's disc minus centre of titanium arc,
(iii) Limb of sun minus centre of sun's disc,
(iv) Negative pole of nickel arc minus centre of nickel arc,
(v) Negative pole of titanium arc minus centre of titanium arc.

The displacements measured are given in Tables IX and X at the end of this bulletin. The limb-minus-arc displacements were obtained by addition of the displacements in (i) and (iii), and in (ii) and (iii) for nickel and titanium respectively.

Experimental Details.

The spectrograph has been described previously[2], but has now an Anderson grating with 9·7 × 12·8 cm. ruled space and 75,085 lines. The third order spectrum was used and the dispersion varied from 0·85 angstroms per mm. at λ 3560 to 0·64 angstroms per mm. at λ 5170. The optical arrangement for photographing sun and arc simultaneously was the same as that employed previously[2] and the device used for photographing the two limbs and the centre of the disc simultaneously was the same as that described in Kodaikanal Observatory Bulletin No. XXXIX. Care was taken that the grating was uniformly illuminated from each of the different light sources whose spectra were required in juxtaposition for measurement of the displacement of the lines. For the adjustment of the limb and centre plates in the micrometer, lines of the iron arc were impressed on the plates but were not used for measuring displacements.

The electric arc was supplied from a battery of 110 volts and burned in air at 580 mm. pressure (the normal atmospheric pressure at the altitude of the observatory). The arc was placed vertical, parallel to the slit, with a length of 10 mm., enlarged to 32 mm. on the slit plate by a condensing lens. The arc length

[1] Kodaikanal Observatory Bulletins Nos. XXXVI, XXXVIII, XXXIX, XLIV, XLVI.
[2] Kodaikanal Observatory Bulletin No. XXXVI.

57.

and current were kept as constant as possible throughout the series of experiments but it will be readily understood that the displacement at the negative pole depends to such a large extent on the instantaneous condition of the arc that the photographs do not form one homogeneous series even though the regions photographed were made to overlap. This does not apply however to the sun-minus-arc determinations, for the wavelength at the centre of a long arc is sufficiently stable for the whole set of photographs of about 100A each to form a homogeneous series.

The arc had generally to be exposed longer than the sun to give easily measurable arc lines, so that the exposures were not always strictly simultaneous, but the exposure in the sun was always made in the middle of the arc exposure without interrupting the latter.

In each region of the spectrum it was found necessary (as also previously with the iron spectrum) to have some photographs with a short exposure on the arc and some with a longer exposure. The stronger arc lines are measured in the short exposure plates and the fainter lines in the long exposure with a sufficient number of lines measured in both to prevent systematic differences being unnoticed. This procedure is necessary in order to avoid making measures on overexposed arc lines, for in my experience it is not possible to set accurately on them and in the case of unsymmetrical lines the measures may not be true owing to the difficulty of distinguishing the position of maximum intensity.

Measurements of each plate were made with the red on the right hand side and again with the red on the left, and were made in duplicate by two measurers.

Many lines are included in Table IX which were not identified by Rowland, but there is little reason to doubt their identity. Rowland missed them perhaps because he did not recognise that lines, nebulous and faint in the arc are generally strengthened in the sun (being high temperature lines) and had no reason to expect such large differences of wavelength between sun and arc which we now know to be due to the unsymmetrical character of spectrum lines.

I.—Nickel Lines.

1. The displacement at the negative pole of the nickel arc.

These displacements, given in Table IX, column 6, each the mean of three determinations, have been measured in the same way as those of iron and other elements described in Kodaikanal Observatory Bulletin No. XL. As there was no supply of pure nickel available, "nickel" coins (value one anna) of the Indian coinage were taken for the arc. The coins are an alloy consisting of 80 per cent of nickel with 20 per cent of copper. A coin was made the lower, negative, electrode and the upper electrode was commercial iron. With this arrangement the arc burned very steadily, more steadily than the arc between two iron electrodes; the iron lines were produced simultaneously and gave a check on the consistency of the results with previous measures of the sun and iron arc. The arc length was 10 mm. throughout, enlarged to 32 mm. on the slit plate, and the current strength $5\frac{1}{2}$ ampères. In order to avoid iron globules adhering to the anna coin when the arc was struck, the electrodes were never brought into contact but the arc was started by inserting a piece of arc carbon between the electrodes.

Except in the region above λ 3900, most nickel lines undergo a large displacement either to the red or to the violet. As in the cases of other elements the lines are displaced in the direction to which they widen unsymmetrically in the arc and those lines which appear symmetrical have zero or small displacements. It is not claimed that the negative pole displacements less than about 0·004A recorded in Tables IX and X are real, but the means of the measures have been given without modification. In some cases where the lines are too faint or diffuse for measurement the direction of the displacement at the negative pole was evident under low magnification and has been noted in the table.

There is a parallelism between the pressure displacements given by Duffield[1] and the displacements at the negative pole but it is very doubtful whether there is any physical relation between the true pressure effect and the negative pole displacement. It seems more than probable that pressure displacements as determined

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[1] Duffield, Phil. Trans. Roy. Soc., 215, 205, 1915.

from increasing the pressure of the atmosphere surrounding the electric arc are, to a greater or less degree depending on the condition of the experiments, not free from the displacements observed at the poles of the arc. Consider, for example, the values given by different experimenters for the pressure shift of the Mount Wilson group *e* of the iron lines which are displaced to the violet at the negative pole. The lines of this group were originally defined as those which shift, and widen unsymmetrically, towards the violet under pressure,[1] and Gale and Adams give the pressure shift of the group in the region λ 5400 to be − 0·014A per atmosphere (i.e., to the violet) in comparing the arc *in vacuo* with the arc at pressures up to 1 or 2 atmospheres.[2] St. John and Babcock, however, comparing the arc *in vacuo* with that at pressures up to 1 atmosphere obtain a value of + 0·0017A per atmosphere (i.e., to the red), at mean wavelength λ 5392 and − 0·0035A per atmosphere (i.e., to the violet) for the lines at mean wavelength λ 3755[3]. St. John and Babcock do not state why their experience differs from that of Gale and Adams working between the same pressures, but one may assume it is because they have had a longer arc, or have avoided the polar regions, or both. It is probable that the values of St. John and Babcock are more free from the pole displacement but it is open to question whether they represent the true pressure shift even now.

It is to be noted that the lines showing decided displacement at the negative pole are generally high temperature lines belonging to those groups which are faint or absent in the furnace spectrum according to the experiments of King,[4] but are not enhanced in the spark.

2. The sun-minus-arc displacements of nickel lines.

These are given in column 7 of Table IX. Only the central portion of a long arc was used for comparison with the centre of the sun's disc.

(*a*) *Relation to negative pole displacements.*—The intimate relation between the displacements in the sun and at the negative pole of the arc is at once evident from Table IX. The lines with a decided shift to the violet at the negative pole are displaced in the sun more to the red than lines with zero or slight shift at the negative pole, and those with a shift to the red at the negative pole are displaced to the violet in the sun or, in a few cases, only slightly to the red. This indicates that the condition of the vapour (probably vapour density[5]) at the centre of a long arc is intermediate between that in the sun and that at the negative pole of the arc. In the following table, the average sun-minus-arc displacements are given for lines classified according to the amount of the shift at the negative pole of the arc. The result of the table is embodied in the accompanying diagram.

TABLE I.—*Relation between sun-minus-arc displacements and negative pole displacements for nickel lines.*

Displacement at negative pole.	Over − ·014A.	− ·014A to − ·004A.	− ·003A to + ·003A.	+ ·004A to + ·014A.	Over + ·014A.
Mean displacement at negative pole ...	− ·0226A.	− ·0090A.	+ ·0005A.	+ ·0108A.	+ ·0225A.
Mean centre-minus-arc displacement .	+ ·0106A.	+ ·0073A.	+ ·0034A.	— ·0043A.	— ·0063A.
Number of lines	7	6	32	23	28

On account of the non-homogeneity in the series of the negative pole shifts referred to previously, it is of no service to attempt to formulate algebraically the law connecting solar displacements and negative pole displacements, but it would seem from the diagram that a displacement to the red at the negative pole results in greater abnormality in the solar displacement than an equal one to the violet would, and that small displacements at the negative pole are proportionately more effective than large displacements.

[1] St. John and Miss Ware, Astrophysical Journal, 36, 14, 1912. [2] Gale and Adams, Astrophysical Journal, 37, 391, 1913.
[3] St. John and Babcock, Astrophysical Journal, 42, 231, 1915. [4] King, Astrophysical Journal, 42, 344, 1915.
[5] Royds, Kodaikanal Observatory Bulletins Nos. XXXVIII and XL.

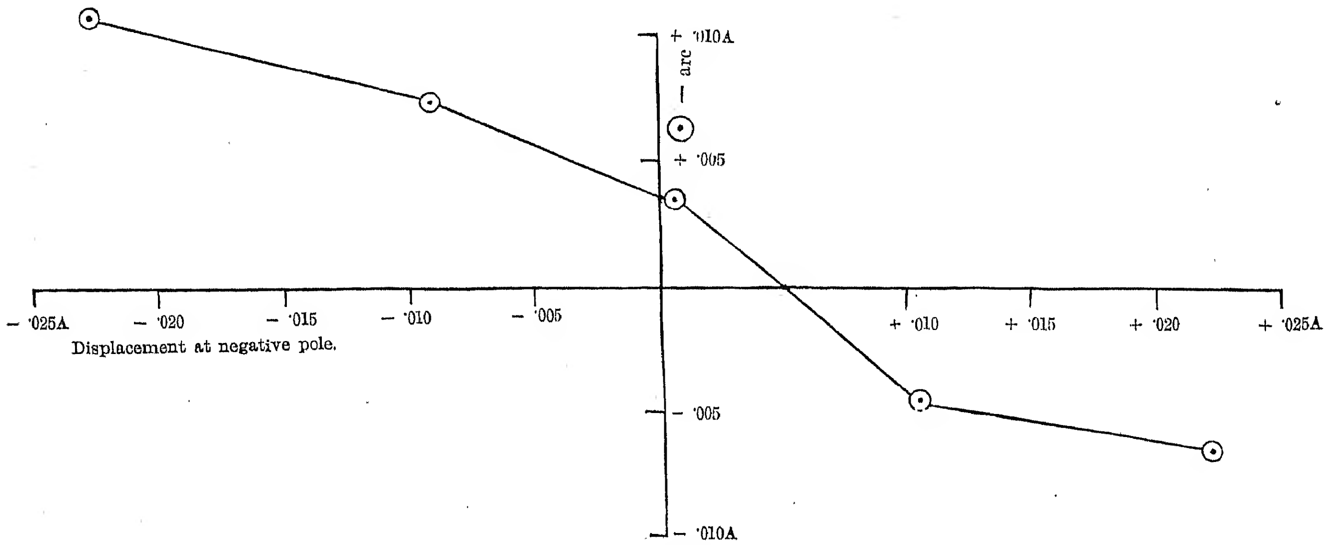

FIG. 1.—RELATION OF SOLAR DISPLACEMENT TO THE DISPLACEMENT AT THE NEGATIVE POLE OF THE ARC.

To the relation expressed in Table I and the diagram there are only 13 exceptions (not included in the table) out of 124 lines with negative pole displacements noted. Perhaps they are due to their being unsuspected blends in the solar spectrum. These 13 exceptions are given below :—

Exceptions to Table I.

λ	Shift at negative pole.	⊙ − arc.
3772·673	+ ·001 A	+ ·019A
3793·745	0	− 7
3913·123	− 2	− 1
4164·804	0	− 2
3670·536	+ 5	+ 5
4006·304	+ 13	+ 15
4284·838	+ 13	+ 4
4325·777	+ 13	+ 6
4401·709	+ 19	+ 4
4459·199	+ 24	+ 4
4925·746	+ 13	+ 6
5099·497	+ 15	+ 4
3724·970	− 17	+ 3

(*b*) *Relation of sun-minus-arc displacement to intensity.*—Mr. Evershed has shown that the stronger iron lines (i.e., high level lines) have larger displacements to the red than the weaker lines, and these displacements were interpreted as Doppler effects due to a descending current at the centre of the sun's disc decreasing with depth. The nickel lines, however, taking account only of those with zero and slight pole displacements, do not show any variation with intensity as the summary in Table II shows.

TABLE II.—*Relation of sun-minus-arc displacements to intensity for nickel lines with zero or slight pole displacements (between* ± 0·003*A) excluding* λλ 3772·673, 3793·745.

Intensity ...	0	1	2	3	4	5	6	7	8	10
Mean ⊙ − arc ...	+ ·0020	+ ·0023	+ ·0032	+ ·0022	+ ·0028	+ ·0037	+ ·0023	+ ·0040	+ ·0035	+ ·0030
Number of lines ...	2	3	5	6	4	3	6	2	2	1

	Intensities 0–3	Intensities 4–10
Mean intensity ...	1·9	6·0
Mean ⊙ − arc ...	+ 0·0025A	+ 0·0030A
Number of lines ...	16	18

Thus the lines of mean intensity 6·0 have a mean displacement larger than that of lines of mean intensity 1·9 by the doubtful amount of 0·0005 A. According to St. John[1] lines of nickel and iron of equal intensity originate at the same level in the sun, and consequently we must expect equal displacements if due to Doppler effects. The absolute displacements of the nickel lines, + 0·0028A for mean intensity 4·1 are in good agreement with those of the iron lines[2] between intensities 2 and 7, namely + 0·0031A, mean intensity 3·9.

The variation of the displacement between lines of mean intensity 1·9 and 6·0 is small, in agreement with the results for iron lines of like intensity but the strongest nickel lines in the above table would have been expected to give larger displacements. Perhaps the reason for this discrepancy is to be found in the fact that the nickel lines although almost or quite symmetrical in the arc at atmospheric pressure are really unsymmetrically widened towards the red, only becoming obviously so under pressure as shown for almost every line in column 5, Table IX, from the data of Duffield[3] and Bilham.[4] It should be remembered, however, that the nickel lines on the whole originate at lower levels than the iron lines which have been studied, and there is some evidence with the iron lines that the variation with intensity becomes less at the lower levels.

(*c*) *Pressure in the sun.*—A relationship could also be traced between the sun-minus-arc displacements and the pressure shift, giving indications of nearly zero pressure in the sun if all lines are considered, but this apparent relation is principally due to the dependence of the pressure shifts of unsymmetrical lines on the shift at the negative pole. At present we can only make use of the lines which undergo zero and slight shifts at the negative pole, although even these lines seem, from what has been said in (*b*), to be under suspicion. The range of the pressure shifts for these lines is small but they can be divided into two groups of more and less affected lines and the mean displacements for the two groups are given in Table III.

TABLE III.—*Solar pressure deduced from lines with negative pole shifts between* ± 0·003*A*, *excluding* λλ 3772·673, 3793·745, 4855·600.

——	Less affected lines.	More affected lines.
Pressure shift per atmosphere.	+ 0·0011A	+ ·0024A
⊙ – arc displacement ...	+ 0·0032A	+ ·0032A
Number of lines	15	16

There is no difference in the solar displacement for the two groups of symmetrical lines with a relative difference of pressure shift of 0·0013A per atmosphere. The solar pressure is therefore equal to the pressure of the atmosphere at the altitude of the observatory. This result is in agreement with the pressure deduced from the symmetrical iron lines.

3. *Displacement of nickel lines at the sun's limb.*

It is seen from column 9 of Table IX that the limb-minus-centre displacements are more regular than the centre-minus-arc displacements; Mr. A. A. Narayana Ayyar has shown[5] that lines with very large centre-minus-arc displacements have normal values for the limb-minus-centre displacement and the values for nickel confirm this. There seems to be no connection whatever between limb-minus-centre displacements and the unsymmetrical character of the lines as evidenced by the shift at the negative pole.

(*a*) *Relation to intensity.*—Only 21 lines with slight shift at the negative pole are available and their mean limb displacement is given in Table IV. As, however, there seems to be no abnormality depending on pole displacements the means of all lines irrespective of the value of their pole shifts have been given in Table V.

[1] St. John, Astrophysical Journal, 38, 341, 1913.
[2] Kodaikanal Observatory Bulletin No. XXXVIII.
[3] Duffield, Phil. Trans. Roy. Soc., 205, 215, 1915.
[4] Bilham, Phil. Trans. Roy. Soc., 214, 359, 1914.
[5] Narayana Ayyar, Kodaikanal Observatory Bulletin No. XLIV.

TABLE IV.—*Relation of limb-minus-centre and limb-minus-arc displacements to intensity for lines with negative pole shift between* ± 0·003*A*.

Intensity	0	1	2	3	4	5	6	7
Limb − centre ...	·0000	+ ·0045	+ ·0026	+ ·0050	+ ·0085	+ ·0065	+ ·0045	+ ·0035
Centre − arc[1] ...	+ ·0020	+ ·0023	+ ·0032	+ ·0022	+ ·0028	+ ·0037	+ ·0023	+ ·0040
Limb − arc	+ ·0020	+ ·0068	+ ·0058	+ ·0072	+ ·0113	+ ·0102	+ ·0068	+ ·0075

TABLE V.—*Relation of limb-minus-centre displacements to intensity for all lines.*

Intensity	0	1	2	3	4	5	6	7
Limb − centre ...	+ ·0014	+ ·0034	+ ·0034	+ ·0044	+ ·0048	+ ·0056	+ ·0043	+ ·0035
Centre − arc[2] ...	+ ·0020	+ ·0023	+ ·0032	+ ·0022	+ ·0028	+ ·0037	+ ·0023	+ ·0040
Limb − arc	+ ·0034	+ ·0057	+ ·0066	+ ·0066	+ ·0076	+ ·0093	+ ·0066	+ ·0075

From these two tables there is slight evidence of the variation of the limb-minus-centre displacement with intensity which was found with the iron lines. Except for the lines of intensity 0, the variation is so small as to be of doubtful reality, however. The absolute values of the displacements are slightly smaller than those of the iron lines at the same level.

(*b*) *Relation to wavelength.*—There is a slight variation of the limb-minus-centre displacement with wavelength, the mean for lines from λλ 3662 to 4490 being + ·0025A and that from λλ 4513 to 5160 being + ·0036A.

(*c*) *Limb-minus-arc displacements.*—If the limb-minus-arc displacements are obtained by adding the limb-minus-centre shifts to the centre-minus-arc shifts the results are seen to be mainly dependent on the influence of the negative pole displacement on the last mentioned. Taking, therefore, the centre-minus-arc displacements of only those lines which have zero or slight displacements at the negative pole, the relationship of the limb-minus-arc displacements with intensity is shown in Tables IV and V. As was to be expected from the approximate uniformity in both limb-minus-centre and centre-minus-arc displacements, the resultant limb-minus-arc displacement is also nearly constant.

The absolute values of the limb-minus-arc displacements of nickel lines are smaller than those of iron lines due to smaller values for both limb-minus-centre and centre-minus-arc.

II.—TITANIUM LINES.

1. *The displacement at the negative pole of the titanium arc.*

The arc spectrum of titanium was obtained by feeding small quantities of titanium metal on to the lower, negative, electrode of a carbon arc. The determination of the displacement at the negative pole was confined to a few regions containing strong lines as the supply of titanium was insufficient for the complete spectrum. On account of the surprising brilliancy of the luminous spot near the negative pole the lines are usually overexposed in the few photographs obtained, and the measurements are consequently not so accurate as is desirable. The arc length was 10 mms., and the current strength 6 ampères.

The displacements at the negative pole of the titanium arc are given in Table X, column 4. It is seen that the majority of the lines investigated give appreciable displacements at the negative pole, mostly to the red, and the displacements seem to have no relation to the pressure shifts.

2. *The sun-minus-arc displacements of titanium lines.*

These are given in column 5 of Table X.

(*a*) *Relation of sun-minus-arc displacements to negative pole displacements.*—As in the case of nickel, the shifts at the negative pole are seen to account for most of the deviations from normal displacement. Grouping the lines according to the direction and amount of their pole shift a relation similar to that for the nickel lines is obtained in Table VI.

[1] The centre-minus-arc displacements are derived from a larger number of lines in some cases.
[2] The centre-minus-arc displacements are derived from lines with slight pole displacement only.

TABLE VI.—*Relation between sun-minus-arc displacements and negative pole displacements for titanium lines.*

Displacement at negative pole	− ·008A to − ·004A	− ·003A to + ·003A	+ ·004A to + ·010A	Over + ·010A
Mean displacement at negative pole ...	− ·0063A	+ ·0005A	+ ·0063A	+ ·0188A
Mean sun-minus-arc displacement ...	+ ·0030A	+ ·0030A	+ ·0021A	− ·0024A
Number of lines	3	13	22	9

(*b*) *Relation of sun-minus-arc displacements to intensity.*—The range of intensities of titanium lines is less than that of either nickel or iron. All lines were taken into consideration as the pole shifts are not known throughout the spectrum and the means are given in Table VII.

TABLE VII.—*Relation of sun-minus-arc displacements to intensity for all titanium lines except* λ 5025·749.

Intensity	00	0	1	2	3	4	5
Centre − arc	− ·0015	+ ·0017	+ ·0002	+ ·0024	+ ·0031	+ ·0021	+ ·0040
Number of lines	2	12	16	26	20	10	1

Mean intensity	0·4	2·4	4·1
Centre − arc	+ ·0007	+ ·0027	+ ·0024
Number of lines	30	46	11

According to St. John the lines of titanium originate at the same level as iron lines of intensity higher by one unit. Above intensity 2, the absolute value of the mean displacement is in satisfactory agreement with that for nickel and iron, but below intensity 2, the shifts are smaller than expected. Perhaps the exclusion of all lines exhibiting pole shift would rectify this.

(*c*) *Pressure in the sun.*—On account of the dependence of the solar displacements on the pole displacements and also on account of the paucity of lines with small displacements at the pole it is of little service to attempt to deduce the pressure in the sun from the relative shift of the more and less affected lines of titanium. The result however, as in the case of nickel, taking all lines into account is in the neighbourhood of absolute zero pressure in the sun, but this is not believed to represent the true solar pressure, because lines exhibiting pole displacements have not been excluded.

3. *Displacement of the titanium lines at the sun's limb.*

The limb-minus-centre displacements are fairly regular for the titanium lines also. For lines above intensity 2, the displacements are practically independent of intensity, as shown in Table VIII.

All lines have been taken into consideration on account of the incompleteness of the determination of the negative pole displacements.

TABLE VIII.—*Relation between limb displacements and intensity for all titanium lines.*

Intensity	00	0	1	2	3	4	5
Limb − centre	·0000	+ ·0030	+ ·0008	+ ·0036	+ ·0029	+ ·0037	+ ·0040
Centre − arc	− ·0015	+ ·0017	+ ·0002	+ ·0024	+ ·0031	+ ·0021	+ ·0040
Limb − arc	− ·0015	+ ·0047	+ ·0010	+ ·0060	+ ·0060	+ ·0058	+ ·0080
Number of lines	2	12	17	26	20	10	1

The absolute values of both limb-minus-centre and limb-minus-arc displacements are smaller than those for the iron lines at the same level in the sun. The smallness of the latter displacement is probably principally due, as in the case of nickel, to the abnormality of the centre-minus-arc displacements on account of the unsymmetrical character of the lines in the arc.

My best thanks are due to Mr. A. A. Narayana Ayyar, B.A., Third Assistant, who has done the bulk of the measurement of the plates, and to Mr. G. Nagaraja Ayyar, Second Assistant ; also to Mr. S. Sitarama Ayyar, B.A., First Assistant, who was able to make some measures before he went to Kashmir.

I would also express my indebtedness to Mr. J. Evershed, F.R.S., the Director, for his interest and valuable criticisms.

SUMMARY.

1. The majority of nickel lines show abnormal displacements in the spectrum of the centre of the sun's disc owing to their unsymmetrical character in the arc as evidenced by the displacement at the negative pole of the arc. The deviation of the solar displacements from normal is in the opposite direction to the displacement at the negative pole, showing that the condition (vapour density, probably) at the centre of the arc is intermediate between that in the sun and that at the negative pole of the arc. Conclusions can consequently only be drawn, at present, from those lines which have zero or slight displacement at the negative pole. Since even these lines, or at any rate most of them, become obviously unsymmetrically widened in the arc under pressure there is possibly still some abnormality in their solar displacement, and this fact may account for the slight discrepancies when compared with the symmetrical iron lines. Consequently, it can only be said that the conclusions from the displacements of the nickel lines (and of the titanium lines, for similar considerations apply to titanium also) are not inconsistent with those drawn for the iron lines.

2. Taking only those nickel lines with zero or slight displacement at the negative pole of the electric arc, the mean centre-minus-arc displacement is practically identical with that of the symmetrical iron lines originating at the same level in the sun, but shows no variation with intensity (i.e., with depth in the reversing layer) as would have been expected from the results for iron. On the whole, however, the nickel lines originate at lower levels than the iron lines which have been studied and with the latter there is evidence that the variation with intensity is less at the lower levels.

3. Again taking nickel lines with zero or slight displacement at the negative pole, the solar pressure, estimated from the relative shift of the lines more and less affected by pressure, is about three-quarters of an atmosphere, in agreement with that deduced from the symmetrical iron lines.

4. The relation between the negative pole displacement of the nickel lines and the centre-minus-arc displacement has been roughly formulated and is shown in fig. 1.

5. The limb-minus-centre and the limb-minus-arc displacements also vary but slightly with intensity. The absolute values are smaller than those of the iron lines.

6. The displacements of the titanium lines are similar to those of the nickel lines. The displacement at the negative pole of the arc is again a disturbing factor.

7. The conclusions drawn from the investigation of the iron lines, namely, that the displacements at the centre of the sun's disc and at the sun's limb are Doppler effects due to descending motion in the line of sight and that the solar pressure is of the order of three-quarters of an atmosphere, are not modified by the investigation of the nickel and titanium lines.

THE OBSERVATORY, KODAIKANAL,
2nd December, 1916.

T. ROYDS,
Assistant Director.

TABLE IX.—*Nickel lines.*

Serial number. (1)	λ (2)	Intensity. (3)	Character. Atmospheric arc. (4)	Character. Under pressure. (5)	Shift at negative pole. (6)	Centre − arc. (7)	Limb − centre. (8)	Limb − arc. (9)	Pressure shift per atmosphere. (10)	Remarks. (11)	Number of plates. Centre − arc. (12)	Number of plates. Limb − centre (13)	Serial number. (14)
					A/1000	A/1000	A/1000	A/1000	A/10000				
1	3561·898	3	...	..	+ 2	+ 1	...	..	7		3	...	1
2	66·522	10	(ur), R	..	− 1	+ 3	...	...	21		3	...	2
3	72·014	6	(ur), R	ur (B)	+ 1	+ 3	...	...	19		3	...	3
4	88·084	6	...	ur (B)	+ 1	+ 5	...	...	11		3	...	4
5	97·854	8	(ur), R	ur	0	+ 3	...	...	21		3	...	5
6	3602·559	4	...	ur	0	0		...	18		3	...	6
7	09·467	5d?	.	...	+ 1	+ 3	...	...	10		3	...	7
8	10·647	5	(ur), R	ur (B)	− 1	+ 5	...	...	22		3	...	8
9	12·882	6d?	...	ur	+ 1	+ 1		...	14		3	...	9
10	19·539	8	(ur), R	ur	− 2	+ 4	...	...	26		3	...	10
11	24·873	4	...	ur	+ 1	+ 3	..	...	8		3	...	11
12	30·045	1	n	uv	−43	+ 9	...	...	...		3	...	12
13	41·784	1	...	...	+ 3	+ 2	...	...	...		4	...	13
14	62·096	3		ur	0	+ 6	+ 4	+10	11		3	3	14
15	64·234	5d?	...	ur	+ 3	+ 4	+ 7 ?	+11 ?	17		3	3	15
16	69·381	4	...	ur	− 1	+ 7	+ 6 ?	+13 ?	13		3	2	16
17	70·566	5	...	ur	+ 5	+ 5	+ 6	+11	21		3	3	17
18	74·287	4		ur	+ 3	+ 1 ?	...	...	17		3	...	18
19	3724·970	1	n	uv	−17	+ 3	+ 1	+ 4	I		2	3	19
20	36·958	3	..	ur (B)	+ 2	+ 3	...	...	16		3	...	20
21	39·370	3	...	...	0	+ 2	+ 6	+ 8	12		3	3	21
22	62·758	...1	n	...	large +	−21	+ 2	−19	...		3	3	22
23	72·673	2	...	...	+ 1	+19	− 1	+18	11		3	3	23
24	75·717	7	...	ur (B)	− 1	+ 4	+ 4	+ 8	15		2	3	24
25	78·203	2	...	...	0	+ 1	+ 2	+ 3	9		3	2	25
26	83·674	6	...	..	0	+ 1	+ 6	+ 7	13		3	3	26
27	92·482	1	...	...	+ 2	+ 3	+ 5	+ 8	10		3	3	27
28	93·745	4	...	ur	0	− 7	+11	+ 4	19		3	3	28
29	3807·293	6	(ur), R	ur (B)	0	+ 1	+ 3	+ 4	15		3	3	29
30	31·837	6	...	ur	+ 2	+ 3	+ 4	+ 7	47		3	3	30
31	44·378	C 4d?	...	..	large +	−30	+ 2	−28	22		3	3	31
32	58·442	7	(ur), R	ur	− 2	+ 4	+ 3	+ 7	21		5	3	32
33	63·201	...1	n, (ur)	ur	+ 8	− 1	+ 4	+ 3	I		6	3	33
34	89·810	2	n, (ur)	ur	+ 6	− 1	+ 4	+ 3	25	p Ni.	3	3	34
35	3909·064	...1	nn	...	...	−16	+ 7	− 9	I		2	3	35
36	12·445	Ni ? 2	nn	...	...	−29	+ 3	−26	I		2	3	36
37	13·123	2	...	...	− 2	− 1	+ 6	+ 5	I		2	3	37
38	70·631	1	nn	...	+24	− 8	+ 6	− 2	I		4	3	38
39	72·313	2	...	...	0	+ 7	+ 4	+11	8		4	3	39
40	73·702	Ni,Zr3	...	ur	0	+ 4	+ 5	+ 9	19		5	3	40
41	74·774	2	nn	...	+14	−28	+ 3	−25	I		4	3	41
42	4006·304	1	n, (ur)	...	+13	+15	+ 5	+20	...		4	3	42
43	17·724	Ni ? 1	(uv)	...	large − ?	+35	+ 1 ?	+36 ?	...		4	1	43
44	64·515	1	nn, (ur)	ur	+14 ?	−15	+ 2	−13	II		3	1	44
45	86·283	...0	nn	...	−27	+15	− 1	+14	...		3	1	45
46	4116·138	...0	n	...	+ 6	− 7	+ 1 ?	− 6 ?	15		3	2	46
47	42·465	...2	n, (ur)	ur	+36	−19	+ 1	−18	II ?		3	3	47
48	64·804	..0	...	...	0	− 2	0 ?	− 2 ?	I		3	3	48
49	84·641	...0	...	ur	+11	0	+ 2	+ 2	II		3	3	49
50	95·684	...1	ur	ur	+10	−19	+ 4 ?	−15 ?	78		3	3	50
51	4200·611	1	n, (ur)	ur	+ 9	− 1	− 2	− 3	82		3	3	51
52	31·183	4 N	n, ur	ur	+36	−21	+ 4	−17	II		3	3	52
53	84·838	1	(n)	ur	+13	+ 4	0	+ 4	95		3	3	53
54	88·149	1	(n), (ur)	ur	+24	− 9	+ 4	− 5	109		3	3	54
55	96·044	1	n, ur	ur	+27	− 4	+ 6	+ 2	150		3	3	55
56	4325·777	1	(n)		+13	+ 6	− 2 ?	+ 4 ?	...		3	3	56
57	31·811	2	...	...	0	+ 5	+ 2	+ 7	30 ?		3	3	57
58	56·163	0	n, ur	ur	+44	−15	+ 1 ?	−14 ?	II	Appears also under pressure group I.	2	2	58
59	68·462	0	(n), ur	ur	+15	− 6	+ 5	− 1	II		1	1	59
60	84·698	0	(n)	ur	+15	− 4	− 1	− 5	II		3	2	60
61	99·776	0	(n), ur	...	+10	− 6	+ 5	− 1			1	3	61
62	4401·020	0	n	ur	+28	−15	0	−15	...		3	3	62
63	01·709	2	...	...	+19	+ 4	+ 4	+ 8	120		2	3	63

TABLE IX.—*Nickel lines*—cont.

Serial number. (1)	λ (2)	Intensity. (3)	Character. Atmospheric arc. (4)	Character. Under pressure. (5)	Shift at negative pole. (6)	Centre — arc. (7)	Limb — centre. (8)	Limb — arc. (9)	Pressure shift per atmosphere. (10)	Remarks. (11)	Number of plates. Centre — arc. (12)	Number of plates. Limb — centre. (13)	Serial number. (14)
					A/1000	A/1000	A/1000	A/1000	A/10000				
64	4410·683	2	n, uv	...	−13	+17	+ 1	+18	...		3	3	64
65	37·729	..	n, u	...	+37	−17	0	−17	117		2	3	65
66	59·199	2	...	ur	+24	+ 4	+ 3	+ 7	109		2	2	66
67	62·621	1	...	ur	+24	− 4	+ 3	− 2	95		3	2	67
68	66·548	0	n	...	large +	−25	+ 2	−23	...		1	1	68
69	70·648	Ni-Zr 2	...	ur	+26	− 3	+ 2	− 1	110		2	3	69
70	73·095	Ni ? 0	...	...	small	+ 4	+ 4	+ 8	...		1	3	70
71	90·701	0	n	uv	large −	+24	+ 2	+26	I	broad in ⊙	2	3	71
72	4513·164	0	...	ur	...	− 4	+ 2	− 2	II	Appears also under pressure group I.	3	2	72
73	20·157	0	...	...	+ 2	+ 6	0	+ 6	17		3	2	73
74	47·101	1	n, ur	...	+27	− 9	+ 4	− 5	...		5	3	74
75	47·401	0	...	...	+14	− 2	− 5	− 7	...		4	3	75
76	51·399	0	n	ur	+23	− 9	+ 6 ?	− 3 ?	II		4	3	76
77	53·346	0	...	...	...	...	+ 3	...	...		...	3	77
78	92·707	2	ur	ur	+16	− 4	+ 2	− 2	103		5	3	78
79	4600·541	2	...	ur	+16	− 4	+ 3	− 1	93		4	3	79
80	05·171	3	ur	ur	+16	+ 1	+ 3	+ 4	95		3	3	80
81	48·835	4	ur	ur	+10	− 2	+ 5	+ 3	114		4	2	81
82	67·159	1	...	...	+ 8	− 6	+ 2	− 4	89		3	2	82
83	67·941	1	...	...	+ 7	− 1	+ 5	+ 4	92		4	1	83
84	86·395	3	...	ur	+15	− 1	+ 6	+ 5	117		4	2	84
85	4701·714	1	...	ur	+26	− 7	+ 5	− 2	135		4	2	85
86	03·994	3	n	uv	− 6	+ 6	+ 3	+ 9	I		3	2	86
87	15·946	4	...	ur	+15	− 5	+ 2	− 3	111		4	2	87
88	31·984	1	...	ur	+ 6	+ 2	+ 3	+ 5	89		3	2	88
89	32·640	1	n	ur	+21	− 5	+ 2	− 4	II		3	2	89
90	52·289	2	n	...	...	−14	+ 4	−10	...		3	2	90
91	52·613	3	n	uv	−17	+11	+ 4	+15	I		3	3	91
92	54·949	1	...	ur	+16	− 1	+ 3	+ 2	96		3	2	92
93	56·705	3	ur	ur	+15	− 1	+ 4	+ 3	113		3	2	93
94	62·820	1	...	...	+ 1	+ 2	+ 4	+ 6	47		3	3	94
95	86·472	0	...	ur	...	+ 3	+ 2	+ 5	106		3	3	95
96	86·727	3	ur		+14	+ 1	+ 4	+ 5			3	3	96
97	4807·179	2	...	ur	+18	0	+ 4	+ 4	117		3	1	97
98	29·214	3	n, ur	ur	+14	− 8	+ 4	− 4	62		3	1	98
99	31·365	3	ur	ur	+18	+ 2	+ 3	+ 5	121		3	1	99
100	55·600	3	n	...	+ 2	0	+ 5	+ 5	62		2	1	100
101	66·465	2	...	ur	+13	+ 1	+ 4	+ 5	122		2	1	101
102	73·630	2	...	ur	+16	− 1	+ 2	+ 1	128		2	2	102
103	4904·597	...3	n, uv	uv	−10	+ 5	+ 6	+11	I		2	1	103
104	18·543	2	...	ur	+13	0	+ 7	+ 7	136		2	1	104
105	25·746	1	...	ur	+13	+ 6	+ 7	+13	II		3	1	105
106	36·015	2	...	ur	+10	− 1	+ 5	+ 4	157		3	1	106
107	37·524	Ni ? 3	n, uv	...	large −	+18	+ 6	+24	I		3	1	107
108	45·622	1	n	...	large + ?	− 8	+ 6	− 2	I		3	1	108
109	53·392	2	...	ur	+14	− 1	+ 6	+ 5	II		3	1	109
110	71·531	Ni- 1	uv	uv	−16	+13	+ 2	+16	I		3	1	110
111	80·352	Ni- 4	n, uv	uv	−14	+ 9	+ 4	+13	I		3	4	111
112	84·297	2	n	uv	− 4	+ 2	+ 4	+ 6	I		3	4	112
113	98·408	1	...	ur	+10	− 1	+ 5	+ 4	II		3	3	113
114	5000·526	Ni- 2	n, uv	uv	−19	+10	+ 4	+14	I		3	3	114
115	12·625	1	...	ur	+14	− 3	+ 4	+ 1	II		3	3	115
116	17·762	3	ur	ur	+14	0	+ 4	+ 4	149		3	3	116
117	18·463	1	n	...	...	−11	+ 6	− 5	...		3	3	117
118	35·542	5	n, uv	uv	−17	+ 7	+ 4	+11	I		3	3	118
119	38·774	Ni ? 2	...	...	large − ?	+11	+ 4	+15	...		1	3	119
120	42·367	1	...	...	large −	+ 6	+ 3	+ 9	I		1	3	120
121	49·035	Ni- 2	...	...	large −	+10	+ 4	+14	I		1	3	121
122	80·714	4	n, uv	uv	−19	+ 9	+ 4	+13	I		3	2	122
123	81·286	2	n	...	− 7	+ 5	+ 2	+ 7	I		3	2	123
124	84·279	3	n, uv	...	large −	+18	+ 4	+22	...		3	2	124
125	99·497	1	...	...	+15	+ 4	+ 2	+ 6	...		1	2	125
126	5100·108	...	n, ur	...	+24	−10	+ 2	− 8	...		1	2	126

TABLE IX.—*Nickel lines*—cont.

Serial number.	λ	Intensity.	Character.		Shift at negative pole.	Centre — arc.	Limb — centre.	Limb — arc.	Pressure shift per atmosphere.	Remarks.	Number of plates.		Serial number.
			Atmospheric arc.	Under pressure.							Centre — arc.	Limb — centre.	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
					A/1000	A/1000	A/1000	A/1000	A/10000				
127	5115·566	2	(ur)	...	+17	+ 2	+ 5	+ 7	...		1	2	127
128	29·546	2	...	...	...	− 4	+ 4	0	...		2	2	128
129	37·250	3	...	...	− 1	+ 1	+ 4	+ 5	...		3	2	129
130	42·958	2	...	...	large − ?	+10	+ 4	+14	...		2	2	130
131	46·659	Ni-3	n	...	large −	+13	+ 5	+18	...		3	2	131
132	55·935	2	...	...	large −	+13	+ 5	+18	...		1	2	132
133	68·832	1	...	...	...	− 6	+ 4	− 2	...		2	3	133

Column 3—Intensity.—The intensities are taken from Rowland's Table of solar wavelengths and unless otherwise noted in this column the line was identified by him as due to nickel only. The dots before the intensity indicate that the line was not identified by Rowland.

Column 4—Character in the arc at atmospheric pressure.—The character in this column was derived from the appearance of the spectrum lines, more particularly at the negative pole. The letters have the following interpretation :—

ur denotes unsymmetrically widened towards the red.
uv denotes unsymmetrically widened towards the violet.
n denotes hazy or diffuse.
nn denotes very hazy or diffuse.
R denotes that the line is reversed at the negative pole.

If the letters are enclosed in brackets the character is only slightly evident.

Column 5—Character in the arc under pressure.—These are taken mostly from Duffield ; the few from Bilham are marked (B).

Column 6—The displacements at the negative pole are derived mostly from three plates.

Column 10—Pressure shift per atmosphere.—The shifts are taken from Duffield's paper. It should be remarked that Duffield has included lines displaced to the violet in the same class as those displaced to the red.

TABLE X.—*Titanium lines.*

Serial number. (1)	λ (2)	Intensity. (3)	Shift at negative pole. (4)	Centre—arc. (5)	Limb—centre. (6)	Limb—arc. (7)	Pressure-shift at 8 atmospheres. (8)	Remarks. (9)	Number of plates. Centre—arc. (10)	Number of plates. Limb—centre. (11)	Serial number. (12)
			A/1000	A/1000	A/1000	A/1000	A/1000				
1	3904·926	3	...	+ 1	+ 3	+ 4	19		3	3	1
2	24·673	4	...	+ 2	+ 4	+ 6	10		2	3	2
3	47·918	2	...	+ 8	+ 9	+17	4		2	3	3
4	48·818	4	...	+ 3	+ 3	+ 6	13		3	3	4
5	62·995	3	...	+ 6	+ 2	+ 8	10		2	3	5
6	64·416	2	..	+ 5	+ 4	+ 9	10		2	3	6
7	81·917	4	...	+ 8	+ 4	+12	16	Probably blend with Fe or impurity in Fe.	2	3	7
8	89·912	4	..	0	+ 2	+ 2	16		2	3	8
9	98·790	4	...	+ 1	+ 6	+ 7	16		5	3	9
10	4024·726	3	...	− 1	+ 3	+ 2	8		3	1	10
11	60·415	1	...	− 4	+ 1	− 3	15		1	1	11
12	64·362	1	...	− 1	− 3	− 4	...		2	1	12
13	78·631	3	...	− 1	0	− 1	5		2	3	13
14	4112·869	1	...	+ 3	− 1	+ 2	14		1	3	14
15	86·280	1	...	+ 1	0	+ 1	16		2	3	15
16	4274·746	2	...	0	+ 3	+ 3	..		2	3	16
17	81·530	0	...	+ 1	+ 3	+ 4	14		2	3	17
18	87·566	1	...	0	+ 2	+ 2	24		4	3	18
19	89·237	2	...	+ 8	+ 6	+14	25		4	2	19
20	98·828	2	...	0	+ 3	+ 3	25		4	3	20
21	99·803	2	...	+ 4	+ 4	+ 8	23		4	3	21
22	4314·964	1	...	+ 2	− 1?	+ 1?	32	? Blend	2	3	22
23	26·520	0	...	0	+ 3	+ 3	29		2	3	23
24	95·201	3	− 1	+ 3	+ 6	+ 9	25	p Ti.	3	3	24
25	4404·433	1 N	+ 5	− 4	− 4	− 8			5	3	25
26	17·450	0	+ 6	+ 6	+ 6	+12	27		3	3	26
27	21·928	00	+12	− 1	0?	− 1?	38	p Ti. Broad in sun.	3	3	27
28	22·985	0	+ 5	0	+ 2	+ 2	28		3	3	28
29	27·266	2	+ 6	+ 3	+ 2	+ 5	17		3	3	29
30	40·515	00	+ 6	− 2	0	− 2	29		3	3	30
31	43·976	5	− 2	+ 4	+ 4	+ 8	21	p Ti.	2	3	31
32	49·313	2	+12	0	+ 1	+ 1	29		3	3	32
33	51·087	1	+14	0	+ 5	+ 5	29		3	3	33
34	53·486	2	+24	− 2	+ 2	0	40		3	3	34
35	53·876	1	− 7	+ 1	+ 1	+ 2	26		3	3	35
36	65·975	1	+ 4	+ 1	+ 2	+ 3	25		3	2	36
37	71·408	0	+ 5	0	+ 1	+ 1	24		7	4	37
38	89·262	0	+ 5	− 1	+ 2	+ 1	29		7	4	38
39	96·318	1	0	+ 5	+ 5?	+10?		? Blend	7	3	39
40	4512·906	3	+ 4	0	+ 2	+ 2	29		7	4	40
41	18·198	3	+ 8	+ 2	+ 2	+ 4	29		4	2	41
42	22·974	2	+ 6	+ 2	+ 5	+ 7	31		4	3	42
43	27·490	3	+ 7	+ 9	− 1	+ 8	29		4	3	43
44	33·419	4	+ 9	+ 2	+ 3	+ 5	44		4	3	44
45	34·953	4	+12	+ 2	+ 4	+ 6	34		4	3	45
46	35·741	3	+10	0	+ 3	+ 3	29		4	3	46
47	36·094	2	+ 3	+ 2	+ 2	+ 4	23		4	4	47
48	36·222	2	+12	+ 1	+ 5	+ 6	31		4	3	48
49	44·864	3	+ 7	+ 2	+ 6	+ 8	31		3	3	49
50	48·938	2	+ 8	+ 2	+ 4	+ 6	31		3	3	50
51	52·632	2	+ 9	+ 1	+ 8	+ 9	29		4	3	51
52	55·662	3	+ 7	+ 2	+ 2	+ 4	29		4	3	52
53	63·939	4	+ 3	+ 2	+ 4	+ 6	34	p Ti.	4	3	53
54	4617·452	3	...	+ 6	+ 1	+ 7	29		2	2	54
55	23·279	2	...	+ 2	+ 4	+ 6	27		2	2	55
56	39·538	2	...	+ 3	0	+ 3	...		2	2	56
57	39·846	2	..	+ 2	+ 3	+ 5	...		2	2	57
58	40·119	1	...	+ 1	0	+ 1	...		2	2	58
59	45·368	0	...	0	+ 3	+ 3	39		2	2	59
60	50·193	0	...	+ 3	+ 3	+ 6	37		2	2	60
61	56·644	3	...	+ 3	+ 4	+ 7	17		2	2	61
62	67·768	3	...	+10	+ 4	+14	20		2	2	62
63	75·294	1	...	− 8	+ 2	− 6	30		2	2	63

TABLE X.—*Titanium lines*—cont.

Serial number.	λ	Intensity.	Shift at negative pole.	Centre–arc.	Limb–centre.	Limb–arc.	Pressure-shift at 8 atmospheres.	Remarks.	Number of plates. Centre–arc.	Number of plates. Limb–centre.	Serial number.
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
			A/1000	A/1000	A/1000	A/1000	A/1000				
64	4682·088	3	...	+ 4	+ 4	+ 8	18		2	2	64
65	98·946	1	...	+ 7	+ 4	+11	37		2	2	65
66	4722·797	0	...	+ 1?	+ 1	+ 2?	36		2	2	66
67	42·979	1	...	+ 2	− 2	0	37		2	2	67
68	58·308	1	...	− 3	+ 2	− 1	27		2	2	68
69	59·463	2	...	+ 2	+ 4	+ 6	31		2	2	69
70	4981·912	4		+ 2	+ 3	+ 5	25		4	3	70
71	91·247	3	− 1	+ 4	+ 4	+ 8	29		4	3	71
72	5014·369	2	− 8	+10 ?	...	...	21		4	..	72
73	16·340	2	0	+ 2	+ 2	+ 4	27		3	3	73
74	20·208	2	− 4	− 2	+ 3	+ 1	29		4	3	74
75	23·052	2	0	+ 3	+ 1	+ 4	28		3	2	75
76	25·027	3	0	0	+ 3	+ 3	27		3	3	76
77	25·749	1	+56	−16	0	−16	...		3	3	77
78	36·645	2	+12	− 3	+ 4	+ 1	42		3	3	78
79	38·579	2	+15	− 3	0	− 3	48		3	3	79
80	40·138	3	− 1	+ 4	+ 3	+ 7	5		4	3	80
81	64·836	3	0	+ 4	+ 2	+ 6	12		4	3	81
82	5145·636	0	+ 5	+ 2	+ 4	+ 6	29		2	2	82
83	47·652	0	+ 7	+ 8	+ 4	+12	17		2	2	83
84	52·361	0	+ 3	0	+ 4	+ 4	18		2	3	84
85	73·917	2	+ 4	+ 7	+ 6	+13	23		4	3	85
86	88·863	2	..	...	+ 4	..	...	p Ti.	...	3	86
87	93·139	2	+ 3	+ 6	+ 4	+10	19		4	3	87
88	5210·555	3	+ 5	+ 4	+ 5	+ 9	16		4	3	88

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Kodaikanal Observatory.

BULLETIN No. LIV.

THE CAUSE OF THE SO-CALLED POLE EFFECT IN THE ELECTRIC ARC.

By T. Royds, D.Sc.

Differences of vapour density were first suggested in Kodaikanal Observatory Bulletin No. XXXVIII as the cause of the displacements of certain lines in different parts and conditions of the electric arc and of the abnormal sun-minus-arc displacements of the same lines. Since, however, direct experimental proof is wanting, and has been said to give negative results, it seems desirable to discuss the evidence and experiments at the point at which work here on the subject has to be given up.

The cause of the displacements in the electric arc has also been treated of by St. John and Babcock[1], Gale and Whitney [2], and Whitney [3], none of whom discuss the evidence and conclusions in Kodaikanal Observatory Bulletins Nos. XXXVIII and XL [4].

In the two latter papers on experiments with a calcium arc, the pole displacement is ascribed to the greater amplitude of vibration of the electrons, and said to depend on the intensity gradient along the arc. The latter phrase is unfortunate as, so far as I understand them, the authors do not mean the rate of change of intensity, but intensity differences.

It must be obvious to every experimenter that the intensity of lines is great in those regions of the arc where displacement occurs, but as it is equally true of lines which do not undergo displacement and of those which are displaced to the red and to the violet one fails to see how the displacement can be said to depend on the intensity differences. One might with equal, or more, truth say that the displacement depends on the width of the spectrum lines, or on their diffuseness, but for reasons which have been already elaborated [5], I believe that the displacement depends on the unsymmetrical character of the spectrum lines. I have not met with a single case where lines whose character was known were not displaced either not at all, to the red, or to the violet according as they were symmetrical, unsymmetrically widened towards the red, or unsymmetrically widened towards the violet, *except under those conditions, e.g., in reversals, where the vapour density has been kept low.* Of course these phenomena, unsymmetrical character, intensity, etc., are not the *cause* of the displacement but are attendant effects due probably to the same cause.

Increased amplitude of vibration of the electrons is suggested by Gale and Whitney[6] as the cause of the displacement in the electric arc, but it is easy to see that this cannot be. The most effective, and probably the only certain, way of increasing the amplitude of vibration of the electrons in the atom is to raise the temperature, but the displacements in the arc are not a temperature effect, for many reasons among which the three following seem sufficient :—

(1) Little is known of the variation of temperature along the arc, but it is certain that the positive pole is much hotter than the negative, whereas under normal conditions the displacement is greatest near the latter. The enhanced lines, which are high temperature lines, appear stronger at the positive pole than at the negative [7], also indicating that the temperature is higher there than at the negative pole.

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[1] St. John and Babcock, Astrophysical Journal, 42, 231, 1915.

[2] Gale and Whitney, Astrophysical Journal, 43, 101, 1916.

[3] Whitney, Astrophysical Journal, 44, 65, 1916.

[4] Both these Bulletins appeared in 1914.

[5] Royds, Kodaikanal Observatory Bulletins Nos. XXXVIII and XL.

[6] *Loc. cit.*

[7] Fowler, M. N. Roy. Astr. Soc., 67, 154, 1907.

(2) The experiments described in Kodaikanal Observatory Bulletin No. XL and here show that the displacement at the negative pole can be varied to any desired extent without reason for believing the arc temperature to be altered in any appreciable degree.

(3) In the sun's reversing layer, where the temperature exceeds that attainable in the arc, the displacement of lines unsymmetrical in the arc is in the direction *opposite* to that of the displacement at the poles of the arc.

Though the evidence given in Kodaikanal Observatory Bulletins Nos. XXXVIII and XL is strongly in favour of density as the cause of the displacements there are many difficulties in the way of direct experimental proof due, primarily, to the difficulty of controlling the vapour density in a source of light. Experiments with different quantities of material such as those giving Gale and Whitney's Tables III and V fail, or at any rate are inconclusive, because there is no reason to believe that the atoms have been separated to a greater distance apart with the smaller amount of material. If the atoms are vaporized in clusters they may not be removed from each other's influence any more than when a larger amount has been used. Exposure times are not a sufficient test of vapour density but only an indication of the total amount of material consumed.

On account of this difficulty it was thought better to use alloys as electrodes. Presumably the molecules in an alloy are so intimately mixed with another metal that each would be surrounded by molecules of another kind and removed from the influence of those of the same kind. Even so, the experiments gave negative results. The best alloys available were the coins of the Indian coinage, the silver coins containing 10 per cent of copper and the nickel coins containing 20 per cent. As the silver coins, and the money they represent, melt away rapidly and do not give a steady arc, most of the experiments were conducted with nickel coins (value one anna). With a nickel coin as one electrode, and the other either another coin, iron or carbon the wavelengths and displacements of the three copper lines $\lambda\lambda$ 4480, 4509 and 4531 were compared with those in the arc between copper electrodes with the same length of arc and current strength. The maximum displacement of the first and last lines was about + 0·05A, and of the second line about + 0·025A. The wavelength at the centre of the alloy arc was identical with that at the centre of the pure copper arc, but it was found that the wavelength of the copper lines at the negative pole could be varied at will by varying the material of the negative electrode. With carbon as the negative electrode and the nickel coin or copper as the positive the displacement of the copper lines at the negative electrode could be made very small, especially with those conditions when the green luminosity surrounding the positive electrode did not reach up to the negative which showed the characteristic blue of the carbon arc. When the nickel coin was negative, and the positive pole either a coin, iron or carbon there is, on the other hand, not the slightest difficulty in obtaining displacements at the negative pole quite as large as those at the negative pole of the arc between two copper electrodes.

The results with the alloy were therefore, in the main, disappointing, especially the fact that the wavelength at the centre of the alloy arc was identical with that at the centre of the pure metal arc. There is however one case, the sodium pair, $\lambda\lambda$ 5682, 5688, where it is possible to obtain a displacement in the same direction as that in the sun and opposite to that usual at the negative pole. The data are given in Kodaikanal Observatory Bulletin No. XL. The solar displacement of these lines, comparing the centre of the sun's disc with the centre of a very long arc is — 0·14A (i.e., to the violet), the displacement of the unreversed line at the negative pole is + 0·36A, whilst the displacement of the *reversal* which occurs at the negative pole is — 0·019A. The sodium pair is very sensitive to displacement and is only a case more extreme than many others found in the Bulletin referred to for which the displacement at the negative pole is much smaller if the lines undergo reversal there than if the line remains unreversed. A new example of this has turned up in the calcium first subordinate triplet near λ 4450. If the lines are reversed at the negative pole the displacement is quite small or zero [1] and the lines appear almost, if not quite, symmetrical [2]. If however the lines are obtained unreversed at the negative pole the displacement amounts to about — 0·012A and the unsymmetrical widening towards the violet is evident.

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[1] Royds, Kodaikanal Observatory Bulletin No. XL.

[2] Royds, Astrophysical Journal XLI, 154, 1915, and Kodaikanal Observatory Bulletin No. XLIII.

I have not met with cases such as that recorded by Whitney where the displacement of the reversal was identical with that of the unreversed lines (it is not so for these same lines on my photographs) but there is nothing impossible in it on the density hypothesis.

The only way in which the results with the alloy and pure metal can be reconciled with the density hypothesis is to suppose that the density differences effective in producing the displacements are of a much higher order than those obtained using the alloy containing 20 per cent of the metal investigated. It would seem that the atoms only influence each other soon after they are torn off from the electrode, as if they occur there in compact clusters which are soon dissipated so that when they reach the centre of the arc the atoms are removed out of each other's influence. In the sun the density is supposed to be so small that a further separation and displacement takes place. If the density effect is due to the mutual electrical fields of the atoms, it is conceivable that the fields of atoms of a different kind would also have an influence thus explaining the considerable displacement at the poles of the alloy arc compared with the pure metal arc.

The considerations of the last paragraph would also explain the negative results of St. John and Babcock but it cannot be conceded without further information that increasing the quantity of metal vaporized increases the vapour density in the furnace in the same ratio. One would have thought that the greater the quantity of material vaporized the greater would be the rate of its removal by condensation on the cooler parts of the tube.

The really interesting result of Gale and Whitney's and of Whitney's experiments is that they have, apparently, succeeded in obtaining arc conditions which bring the normal displacement at the negative pole of the arc down to zero, and even, for the more sensitive lines, in the direction opposite to the usual one, i.e., in the same direction as the sun-minus-arc displacement.

I agree with Duffield's remarks on the influence of density and temperature gradients in light sources on the displacement of spectrum lines [1], but would like to make clear that the gradients cannot have any influence unless density and temperature are themselves causes of displacement.

Although direct experimental proof has not been obtained, I cannot find any hypothesis other than density to explain the displacement of certain spectrum lines in different parts and conditions of the arc and the abnormal sun-minus-arc displacement of the same lines which have been discussed in Kodaikanal Observatory Bulletins Nos. XXXVIII and XL. Whether some additional condition is necessary, or whether the density differences effective in displacing lines are larger than those hitherto attempted, are points for further experiments. It is hoped to construct a source of light where the vapour density can be varied over a large range when it is possible to resume these experiments.

KODAIKANAL OBSERVATORY,
2nd December 1916.

T. ROYDS,
Assistant Director.

[1] Duffield, Phil. Mag. 30, 385, 1915.

Kodaikanal Observatory.

BULLETIN No. LV.

THE SOLAR PROMINENCE OF 1916, MAY 26.

BY J. EVERSHED, F.R.S.

A good series of photographs of this remarkable eruptive prominence was secured by Dr. Royds at Kodaikanal with the Cambridge spectroheliograph, and at Srinagar Kashmir another series was obtained by the author, using the new spectroheliograph installed there in the autumn of 1915. The definition at Kodaikanal was very good at the time of the display, but there were some interruptions from cloud. At Srinagar the conditions were practically perfect throughout the day which was cloudless.

The two series of plates supplement one another, and the development of the prominence can be studied with the quite exceptional advantage of an uninterrupted series of well defined images obtained at short intervals of time. In plate IV, I give a selection of photographs from both observatories illustrating the different stages in the development of the prominence.

In studying spectroheliograph images of a rapidly changing prominence it is necessary to consider the time taken in building up the image by the successive slit sections. Owing to the comparative faintness of the light the slits of the spectroheliograph are made to move slowly across the image (or the image across the slits) and the time when the base of a large prominence is impressed on the plate may differ by a minute or more from the time when the highest parts are photographed. Thus the complete image does not represent the prominence at any one moment of time. In plate IV the times given under each image are the times when the slits reached the base of the prominence.

In estimating movements the exact time the slit reached any particular point of reference in the prominence has to be carefully computed, the speed of the slits, or of the image, being ascertained by noting the time taken in traversing the solar diameter. In the Kodaikanal spectroheliograph this speed was about $6'$ per minute, and the Kashmir spectroheliograph it was $9'$ per minute ; but the two instruments are of different design and the movement is in opposite directions : thus at Kodaikanal the prominence was photographed successively from base to summit, and at Srinagar from summit to base.

In table I, page 215, I give a list of all the photographs taken, with the approximate times the centre of the image was photographed. Of the seventeen exposures only Nos. 3 and 4 were made practically simultaneously at Kodaikanal and at Srinagar ; these images are apparently identical in all details, but comparisons with a " Blink " apparatus would probably reveal slight differences in the higher and also the lower parts of the prominence where the exposure times would differ slightly.

The exposure times of the Srinagar series were determined by a mean time chronometer by Frodsham the error and rate of which was periodically ascertained by solar altitude observations with a sextant. These times are probably correct within one second. The Kodaikanal times are determined from the standard clock of the Observatory the error of which is daily observed by time signal from the Madras Observatory.

General description of the photographs.—Photograph No. 1 of the combined series is a large scale image of the disc obtained with the 40-foot focus objective at Srinagar. This was accidentally over-exposed for the flocculi but shows the prominences rather well. A prominence the denser part of which is $90''$ in height is shown at latitude $+ 48°$ on the east limb and there are also shown bright detached streaks issuing from the

chromosphere at + 63° which extend to over 4′ above the limb, they probably extend much further than this but the plate is under-exposed for the prominences.

In the second photograph exposed at $8^h\ 6^m$ (see plate IV) the denser part of the prominence at + 48° is found to be 136″ in height, and at + 63° there is seen a complicated system of bright streaks connected with the prominence at + 48° and extending over it to a vast height, the highest filaments being over 12′ above the limb.

In Nos. 3 and 4 exposed after an interval of 16 minutes, faint streaks and patches are still found at a height of 12′ above the limb over latitude + 33° but the lower part of this prominence has contracted and brightened (plate IV at $8^h\ 21^m\ 47^s$). The prominence at + 48° now shows signs of rapid development and from this time on the rate of ascent of the upper limit of the prominence increases as is shown in table II.

At $8^h\ 36^m$ the prominence has reached a stage of great brilliance and complexity of structure and would doubtless have presented a magnificent spectacle viewed in the spectroscope in Hα light. Faint whisps can still be traced up to a height of 11′ over the top of the ascending mass.

In the photographs taken at $8^h\ 50^m$, $8^h\ 55^m$, and $8^h\ 57^m$ the main stem of the great eruption turns over at the highest point towards the north, bending round as if to fall back on the sun. There are also three or four branching steamers from the upper part of the column also turning over like the streams of a fountain. Hanging suspended over the more northern prominence, now moved to + 68°, there is a very bright elongated condensation resembling a falling rocket, and there are other bright condensations higher up in the prominence.

At $9^h\ 3^m$ a rapid dissolution of the entire prominence had set in, the main column is shown by the photographs to be breaking up and the "falling rocket" appears very much fainter and has *risen* slightly.

At $9^h\ 9^m$ the main column consists of separate filaments elongated in the direction of the column in the lower part but condensed into roundish spots in the higher region. The larger of these points of light although very small in relation to the prominence as a whole would be roughly 10″ or 7,000 km in diameter. In this plate (one of the Kodaikanal series) the field of view is limited by a circle 15′ above the sun's limb and the top of the prominence is cut off at this height. (The white streaks shown in the photograph are due to a passing cloud diffusing sunlight on to the slit.)

At $9^h\ 19^m$ the entire column has vanished. The spectroheliograph records blank space where ten minutes earlier brightly glowing masses of gas were photographed. There is however a little group of bright points at a height extending from 13′ to 17′ above the limb and these are probably the same as the group photographed in the last plate. In photograph No. 13 exposed at nearly the same time at Kodaikanal the bright points are not seen, being outside the field of the photograph, but a faint remnant can be traced of the "rocket." The ow bright prominence extending from latitude 35° to 48° and the small prominences to the south of it, are just as clearly shown in this photograph as in all the others, proving that no change of adjustment of the K line on the camera slit had occurred.

At $9^h\ 22^m$ photograph No. 14 still shows the group of bright points, but they are much fainter, and have ascended to the enormous height of 16′ to 18·5′ above the limb. This highest point in the group is equal to half a million of miles above the sun, a height which greatly exceeds all our previous records.

In the Kodaikanal photograph No. 15 exposed at $9^h\ 27^m$ very faint remnants of the rocket are still visible although I cannot trace these on the Srinagar plates taken earlier.

In the last two photographs Nos. 16 and 17 obtained at Srinagar it is no longer possible to distinguish faint remnants of the prominence from slight defects in the film. The photographic field extends in the last plate to a distance of over 30′ or about solar diameter from the limb, and at the position which the bright ascending masses might be expected to occupy there are very faint markings on the film, but I hesitate to regard these as parts of the prominence. This last plate shows the low bright prominence extending from latitude +35° to latitude +48° practically unaltered, the immense eruption taking place immediately over its northern end has apparently had no effect whatever on it. This prominence was of a long enduring type and had been visible for several days on the limb, attaining its greatest apparent development on May 24 and 25 when it was 120″ in height. Its last appearence was on May 27.

It is very remarkable that the whole of the eruptive prominence faded away practically simultaneously, not only the main column at latitude +48° but also the prominence about 20° to the north. This had steadily moved northward along the sun's limb between $8^h\ 6^m$ and $8^h\ 57^m$ changing its position by 6° from + 63° to +69°.

The eruption occurred outside the sunspot zones, and in the disc photographs no trace can be seen of any bright flocculus in the region. There is however a dark flocculus unusually well shown on the calcium plates and clearly shown on the Hα plate, which probably was connected with the eruption. On May 25 the flocculus extends from latitude $+34°$ and longitude $19°$ east of the central meridian in an irregular line meeting the limb at latitude $+58°$. On the 26th the western end had advanced towards the central meridian and at $8^h\,9^m$ and $8^h\,12^m$ the eastern end, in the form of a narrow line, meets the limb almost at the base of the big eruption at about latitude 50°. Twenty minutes later the Hα photograph was obtained and on this the portion of the flocculus near the limb has entirely vanished.

Movements in the prominence and velocity of ascent.—A general ascending movement from a height of $130''$ at $8^h\,6^m$ to over $15'$ at $9^h\,9^m$ is obvious (see plate IV). Measures of the upper limits of the ascending mass on the successive plates reveal what is not so obvious that the ascending motion accelerates, the velocity increasing from 79 km/sec to 292 km/sec, as is seen in table II. These measures were made in a direction radial to the sun.

Measures of definite points in the prominence which can be identified on two or more plates have also been made, and in nearly all cases where more than one determination was possible an acceleration is shown. Table III gives the results of these measures. An acceleration of velocity of ascent has been measured in several eruptions previously recorded, notably in the very large prominence of 1907, February 18.[1]

The straightness of the main column seems to imply rapid motion in the direction of the column and this is confirmed by measures of points in and near the column. It was therefore thought best to measure the positions of points at a distance from the column in two co-ordinates, one in the direction of the column and the other at right angles to this. A considerable number of separate determinations of apparent velocity have thus been obtained. The resultant directions of movement and velocities are the projections of the real directions and velocities in a plane normal to the line of vision. There may be and probably are components in the line of sight, but these will be comparatively small, not exceeding about 30 km/sec as will be explained later. These measures are of course only possible in the case of definitely marked spots, not in the case of long drawn out filaments. The results are very interesting; contrary to what might have been anticipated from the close resemblance to a fountain, it appears that all points which can be identified on successive plates are moving radially outward from a point in the chromosphere at the base of the main column.

Taking the mean velocities or those which would result from the first and the last observations of a marking, omitting the intermediate positions, I have represented the movements in the diagram following plate IV. The arrows here show the direction of movement and the relative velocity indicated by the length of the shaft, the actual mean velocities in km/sec are given in figures at the points of the arrows. The general form and details of the prominence are carefully drawn from the photograph exposed at $8^h\,57^m$, a print of the prominence being laid on the drawing paper and the salient points pricked through with a fine pin. The detached fragments above the top of the "fountain" were photographed at $9^h\,22^m$ after the dissolution of the main stem had taken place, and the movement of the lower limit of these fragments was measured in a direction radial to the sun only, the motion at right angles being indeterminate owing to the indefinite boundaries in that direction; the arrow here, therefore, does not truly represent the direction of movement. It is probable that the movement of these fragments was also directed from the same point in the chromosphere as in the other cases. It was the upper faint extensions of these flying fragments that attained the unprecedented height of over $18'$ above the limb.

The highest velocity recorded is not in the highest part of the prominence, but about halfway up the main column where a little bright projecting point could be recognized on photographs Nos. 8 and 9. From the movement in the direction of the column the velocity was found to be 457 km/sec. In the measures a high degree of accuracy is not possible owing to the constant change of form in the details measured, moreover the kaleidoscopic nature of these changes render the identification doubtful in some cases. Possibly they may be relied on to give the order of velocity within 10 or 15 per cent. The true velocities may be slightly greater than the observed since the components in the line of sight are neglected. That these will be relatively small results

[1] Astrophysical Journal, XXVIII, 79.

from the peculiar limitations of the spectroheliograph image which only represents that part of the prominence which has a small or zero motion in the line of sight. With slits of insensible width and perfect adjustment of the spectrum line on the camera slit the image would represent zero motion only, since any increase or decrease of wave-length due to motion would throw the spectrum line off the slit, and the light would not reach the plate at all. But in practice slits of quite considerable width are used in prominence work, and an appreciable range of wave-lengths will therefore reach the plate. In the Kashmir spectroheliograph the camera slit was 0·10 mm in width and the dispersion between H and K being 5 angstroms per millimetre the possible range of wave-length admitted to the plate with a narrow collimator slit will be 0·5A. But the collimator slit was even wider than the camera slit, a width of 0·15 mm being found by experience to give the best results, with this width a displacement of 0·6 angstrom to red or violet will not throw the light entirely off the camera slit although the intensity will be greatly reduced. With the intensity reduced four times only a very feeble impression would be made on the plate, and this would result from a displacement of 0·5A each way or 33 km/sec approach or recession. It is very improbable therefore that any parts of the prominence as photographed had velocities in the line of sight exceeding about one-tenth the velocities found across the line of sight.

In visual observations of a prominence in the spectroscope the parts which have large motions in the line of sight are clearly seen, often projected on the bright continuous spectrum adjacent to the Hα line. At Kodaikanal the prominence of May 26 was observed in the grating spectroscope attached to the 6-inch equatorial by First Assistant S. Sitarama Ayyar, and he noted a displacement of 3A to the red at $8^h\ 50^m$ over the lower half of the prominence, and a slight displacement to violet in the upper part. The largest displacement he observed would imply a velocity of recession of 137 km/sec in the lower part of the main column, and here a drawing would probably have differed somewhat from the photograph.

The "spectro-enregistreur des vitesse" designed by Deslandes would be an invaluable adjunct to the spectroheliograph for the complete determination of velocities in eruptive prominences, but it would need to be worked as an entirely independent installation with a separate heliostat, on account of the very limited time available during the progress of a great eruption.

In the prominence of May 26 the components of motion across the line of sight appear to have been much larger than those in the line of sight, which are relatively of small importance. The striking feature resulting from the measurements is the unexpectedly consistent nature of the motion, all the parts of the prominence being found to be moving radially from the central point situated in the chromosphere at the base of the main stem. The bright rocket-like condensation which gives the impression of falling back towards the sun is in reality moving upward and outward from the main column but with a lesser speed than the higher parts of the prominence, and the prominence 20° to the north of the column is moving horizontally along the sun's surface with the smallest speed of all. The greatest velocity is found in the main column and the movement is here all in the direction of the column. The straightness of this column is remarkable especially in view of the fact that it is inclined 27° to the direction of the solar radius. It bends over at the top but not in the direction one would expect from the action of gravity. The column inclines towards the equator, yet the branching streamers bend back towards the pole : these streamers however possibly represent the projections of more or less spherical shells of luminosity expanding outward from the central point of radiation in the chromosphere.

Discussion of results.—The physical interpretation of the phenomena observed in an eruptive prominence such as that of May 26, 1916, is not easy. The total quantity of matter concerned is probably small and the density almost inconceivably low, as will appear from the following considerations. Prominences in general and the chromosphere from which they arise are certainly cooler than the photosphere, their emissive power being less. This is shown by the strong absorption lines of hydrogen α, β, γ, and the calcium lines H and K in the solar spectrum ; the hydrogen line δ is however comparatively weak, ϵ is almost absent as a dark line, and the rest of the Balmer series in the ultra-violet are entirely missing as dark lines although they are conspicuous emission lines in eclipse spectra. But at the centre of the sun's disc the depth of hydrogen through which the photospheric light has to pass is about 6,000 km and it increases to 90,000 km at the limb, yet no trace of absorption due to these ultra-violet lines occurs in any part of the disc. This behaviour of the hydrogen lines might be due to molecular scattering in the photospheric region reducing the intensity of the

continuous spectrum background, as has been suggested by Schuster.[1] But if this were so, the lines of other elements besides hydrogen might be expected to show a similar tendency to become less dark, or to disappear altogether in the ultra-violet region, which is certainly not the case.

It appears to me more probable that the disappearance of the less absorptive radiations of hydrogen is simply due to insufficiency of material. As in the case of helium, the total quantity of gas in the chromosphere is not sufficient to produce appreciable absorption. The emissive (and absorptive) power of hydrogen increases with the wave-length for the Balmer series of lines, and it may be that the total quantity of gas in the chromosphere is only sufficient to give an intensity of emission and absorption comparable with that of a black body at the same temperature for the three less refrangible lines.

Now it is only by extrapolation that an estimate can be made of the actual emissive power of a black body, or of a gas of sufficient thickness, at solar temperatures, but it is probably greater than that produced in the laboratory by the electrical stimulation of gases. It will perhaps be safe to assume that the emissive power will be at least equal to that of hydrogen in a partially exhausted tube in which an electrical discharge is passing. But with a tube reduced to 1 mm pressure the thickness of gas necessary to give the maximun emission, or absorption, will perhaps be only of the order of a few cm for the less refrangible lines and possibly as much as a metre for the ultra-violet lines of the Balmer series. If this is so, in order to produce the partial absorption ending at Hϵ observed in the chromosphere, the total depth of gas lying above the photosphere must be the equivalent of something less than a meter at 1 mm pressure ; but as it is spread over a depth of 6×10^6 meters the density will be reduced six million times.

The assumption as to the total thickness of gas necessary to give maximum emission and absorption in the laboratory may be varied within very wide limits without altering the conclusion that the partial nature of the hydrogen absorption in the sun indicates an excessively low density. If the hydrogen in the chromosphere had a density approaching that in the vacuum tube at 1 mm pressure it is probable that in a depth of about 180,000 km at the limb the accumulation of feeble radiations between the Balmer lines would produce a continuous emission spectrum instead of the narrow bright lines with clear spaces seen at eclipses.

The same arguments apply with still greater force to the prominences, if we may assume that the radiation is due to heat alone and that Kirchoffs law applies, for only a small proportion are dense enough to produce absorption in the Hα line even when the line of sight passes through a thickness of some 50,000 to 100,000 kilometers. These denser absorbing prominences are also brighter than the average, not because of a higher temperature, but because they approximate to black body radiation which the majority of prominences never attain, notwithstanding the vast depth of space occupied.

We may form a rough estimate of the total mass and of the density of the hydrogen constituent of a prominence assuming that the amount of hydrogen is equivalent to that in a layer one centimeter thick at a pressure of 1 mm of mercury at normal temperature. The equivalent volume of a prominence of say one square minute of arc apparent area, or actually at the sun's distance $18{\cdot}9 \times 10^{18}$ square centimeters, will be $18{\cdot}9 \times 10^{18}$ cubic centimeters, and the mass $2{\cdot}21 \times 10^9$ kilograms.

If the prominence has a thickness which is the equivalent of 1 minute of arc or 43,480 kilometers, the density will be less than that of the gas at 1 mm pressure in the ratio of 1 centimeter to 43,480 kilometers or 4,348 million times. This excessively low density will not affect the emissive power of the prominence since the angular size is the same whatever thickness be assumed. Notwithstanding this extremely low density the number of hydrogen molecules will still be of the order of $8{\cdot}2 \times 10^6$ in a cubic centimeter.

If as is possible the emission under solar conditions is greater than that in the hydrogen tube, the amount of matter present in the prominence and its density must be correspondingly diminished.

Under this condition of excessively low density the prominence matter will of course not conduct electricity as in the discharge tube, that is, we cannot expect to observe electric discharges on a big scale in the prominences. The atoms may indeed carry charges and be impelled by electric forces, although the apparent absence of any Stark effect tells against such a hypothesis. The calcium lines H and K in the prominences are usually very sharply defined narrow lines about 0·10A in width, but they are frequently bent and

[1] A. Schuster, "Radiation through a Foggy Atmosphere," Astrophysical Journal, XXI, 21, 1905.

distorted or bodily displaced by motion, and there is often a tendency to a diffused widening in the higher parts of a prominence. The Hα line is similar but wider, it measures 0·9A in the chromosphere and about 0·4A in the prominences. In neither H and K nor Hα have I met with anything suggesting a separation of the lines into two or more components, but possibly the conditions would not be favourable for the production of a Stark effect even if strong electric fields are actually present in the region immediately above the chromosphere.

There is some evidence that eruptive prominences consist in their earlier stages of unusually dense low-lying gas giving strong absorption in Hα and the calcium lines H_3 K_3. The mass of gas may persist for several days apparently unchanged and then suddenly become unstable, coming under the influence of a force which apparently tears it to shreds and sends the fragments flying into space with accelerating speed. Considering the comparative rarity of these outbursts it is remarkable that another eruption having much the same character as that of May 26 was observed by Buss two days later.[1] This also developed from a dark hydrogen flocculus and is stated to have resembled "a stupendous luminous fountain," it appeared in the same solar quadrant but in a lower latitude, the end of the dark absorption marking as photographed at Kodaikanal in K light being at latitude 26° on the eastern limb. In this case the entire length of the dark flocculus appears to have been dissipated by the eruption, whereas in the prominence of May 26 only the eastern end of a long and straggling flocculus disappeared. The sudden disappearance of Hα absorption markings photographed on the disc of the sun has been noticed on several occasions at Kodaikanal but in positions too far removed from the limb to observe any accompanying eruptive prominence.

The relation between unstable prominences and absorption phenomena has also been observed by A. M. Newbegin especially with regard to absorbing hydrogen when seen in projection on bright prominences.[2]

It would seem from these observations and others I might mention that prominences dense enough to give strong absorption in Hα and the calcium lines H_3 and K_3 are for some reason unstable and liable to sudden explosive dissolution. That the dissipating force lies at the surface of the sun and may be localized in a very limited region appears to be indicated by the radiating movements measured in the photographs of May 26.

The rapidity with which apparently large masses of gas fade away to invisibility may probably be explained by the extremely low density, for each atom of gas occupies so large a volume of space that it is independent of all the others, its mean free path being practically infinite; the gas can thus have no temperature in the ordinary sense, and its emissive power is not dependent on mutual collisions but only on absorption of photospheric radiation, which is apparently insufficient to maintain luminosity at great heights above the sun's surface. The prominence as a whole may continue luminous if a constant supply of gaseous atoms endowed with great internal energy is emitted from the chromosphere, but the moment this supply ceases the prominence would fade. This is suggested by the behaviour of the main stem of the big prominence; this evidently consisted of a stream of rapidly moving gas which maintained a brilliant luminosity during the period when it formed a continuous column, but as soon as the supply of gas from the chromosphere ceased and breaks in the continuity occurred, the separate detached masses faded very rapidly. However an examination of the photographs reveals another feature not readily explained in this way. If the photograph at 8^h 50^m is compared with that taken six minutes later it will be found that some of the detached masses high above the chromosphere such as the "rocket" formation and other bright condensations have increased in luminosity although no connection with the chromosphere is apparent; this almost suggests collision of the moving gases with denser matter already existing in this region.

Another remarkable and at present mysterious feature is the almost simultaneous fading of the entire prominence, already alluded to. When the main column disappeared the subsidiary column 260,000 km to the north of it succumbed also as well as the rocket formation and all its appurtenances, distant some 300,000 km from the main column and an equal distance above the chromosphere.

THE OBSERVATORY, KODAIKANAL,
25th January 1917.

J. EVERSHED,
Director, Kodaikanal and Madras Observatories.

1 The Observatory, XXXIX, 352.

2 Journal of the British Astronomical Association, XXVI, 307.

TABLE I.

Photograph number	Centre of Prominence exposed at	Photographed at
	H. M. S.	
1	7 47 07	Srinagar.
2	8 05 34	Do.
3	8 21 31	Kodaikanal.
4	8 21 33	Srinagar.
5	8 36 06	Do.
6	8 47 15	Kodaikanal.
7	8 49 50	Srinagar.
8	8 55 18	Do.
9	8 57 32	Kodaikanal.
10	9 04 06	Do.
11	9 10 45	Do.
12	9 18 40	Srinagar
13	9 20 16	Kodaikanal.
14	9 22 37	Srinagar.
15	9 27 31	Kodaikanal.
16	9 42 12	Srinagar.
17	9 47 52	Do.

The times are 5½ hours fast on Greenwich civil time.

TABLE II.—GENERAL MOVEMENT OF ASCENT OF THE PROMINENCE

Photograph number	Time	Interval	Motion radial to sun	
	H. M. S.	M. S.	"	KM/SEC
2	8 05 34			
		15 46	100	79
4	8 21 20			
		14 24	184	157
5	8 35 44			
		13 10	219	203
7	8 48 54			
		5 10	123	292
8	8 54 04			

The velocities in direction of column are about 5 per cent greater.

TABLE III.—MOVEMENTS OF PARTS OF THE PROMINENCE

A.—Movements measured parallel to column

Photograph number	Time	Interval	Motion parallel to column	
	SPOT NEAR BASE OF COLUMN			
	H. M. S.	S.	″	KM/SEC
6	8 46 30			
		244	63	189
7	8 50 34			
	PROJECTING POINT ON COLUMN			
8	8 55 20			
		122	76	457
9	8 57 22			
	ARROW LIKE MARKING NEAR COLUMN			
6	8 46 45			
		215	64	218
7	8 50 20			
		300	101	247
8	8 55 20			
		125	72	423
9	8 57 25			
	Whole interval ...	640	237	272
	STREAMER NEAR TOP OF COLUMN			
7	8 49 42			
		296	133	329
8	8 54 38			
		212	85	296
9	8 58 10			
	Whole interval ...	508	218	316

B.—Motion measured radial to sun

Photograph number	Time	Interval	Motion radial to sun	
	DETACHED REMNANTS OF PROMINENCE			
	H. M. S.	S.	″	KM/SEC
13	9 18 45			
		232	100	319
15	9 22 37			

C.—Movements measured in two co-ordinates

Photograph number	Time H.	M.	S.	Interval s.	Motion parallel to column ″	KM/SEC	Motion at right angles to column ″	KM/SEC
				BRIGHT POINT UNDER THE ARCH.				
7	8	50	14					
				303	118	285	47	115
8	8	55	17					
				137	63	335	28	152
9	8	57	34					
	Whole interval ...			440	181	302	75	127
							Resultant mean velocity	328 km/sec
				BRIGHT CONDENSATION ABOVE THE ROCKET-LIKE MARKING				
6	8	47	05					
				187	23	89	19	75
7	8	50	12					
				308	57	136	48	113
8	8	55	20					
				125	32	190	23	134
9	8	57	25					
				403	81	148	97	176
	9	04	08					
	Whole interval ...			1023	193	139	187	133
							Resultant mean velocity	192 km/sec
				ROCKET-LIKE MARKING				
7	8	50	34					
				317	6	13	36	84
8	8	55	51					
				71	8	78	19	197
9	8	57	02					
				404	34	62	80	145
10	9	03	46					
	Whole interval ...			792	48	44	135	125
							Resultant mean velocity	132 km/sec

D.—Motion of prominence at latitude 65° — 69°

Photograph number	Time H.	M.	S.	Latitude of base °
2	8	06	32	63
3	8	20	55	65½
5	8	36	47	66
6	8	45	55	67½
7	8	51	23	68
8	8	56	51	69
10	9	02	43	69
11	9	09	06	68

Motion between $8^h\ 21^m$ and $8^h\ 57^m = 3\frac{1}{2}$ degrees of latitude in 36 minutes, equivalent to 20 km/sec tangent to sun.

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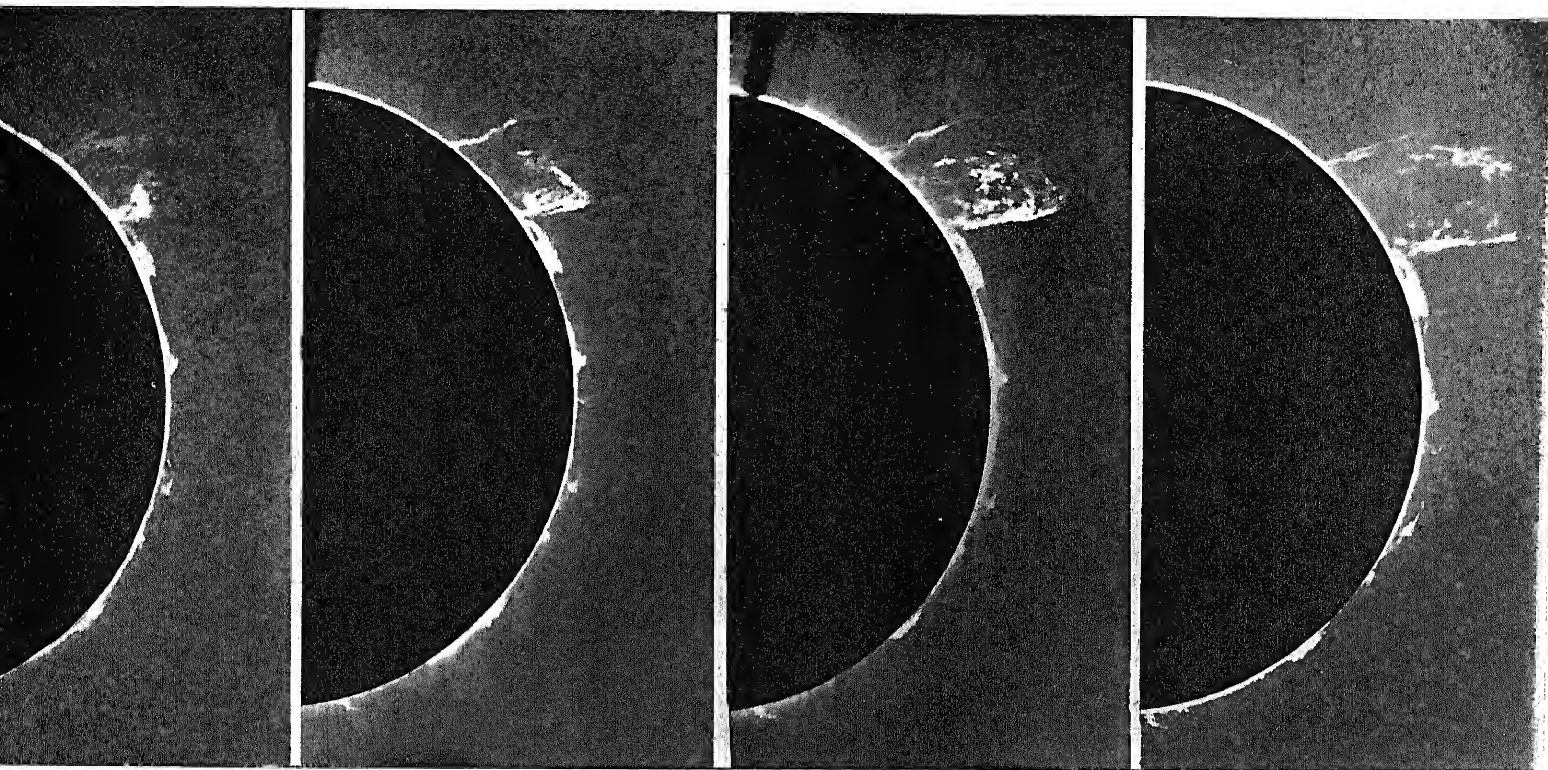
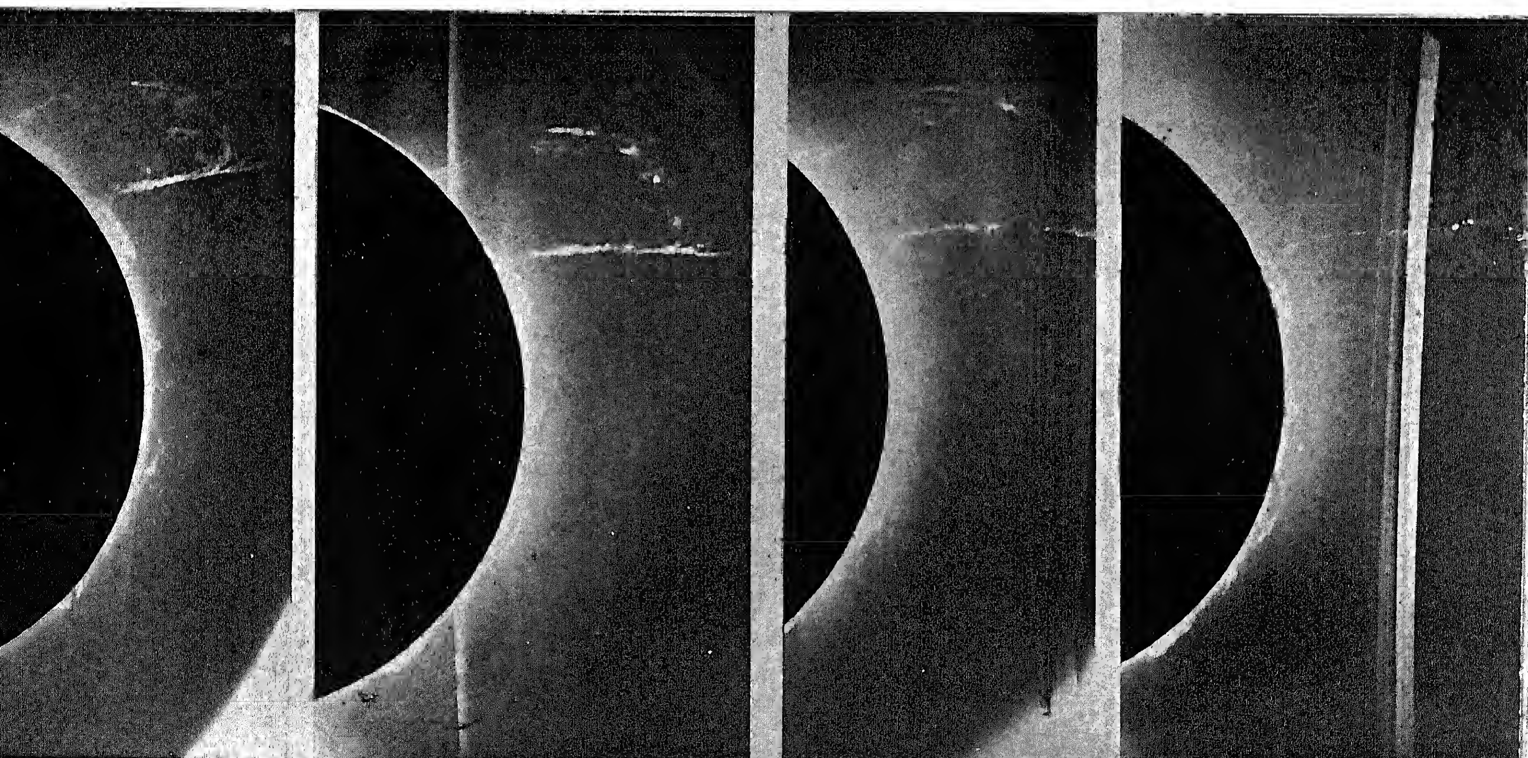


8h 6m 12s 8h 21m 47s 8h 36m 29s 8h 46m 25s



8h 50m 40s 8h 56m 40s 9h 3m 19s 9h 9m 34s

ERUPTIVE PROMINENCE
1916 May 26.

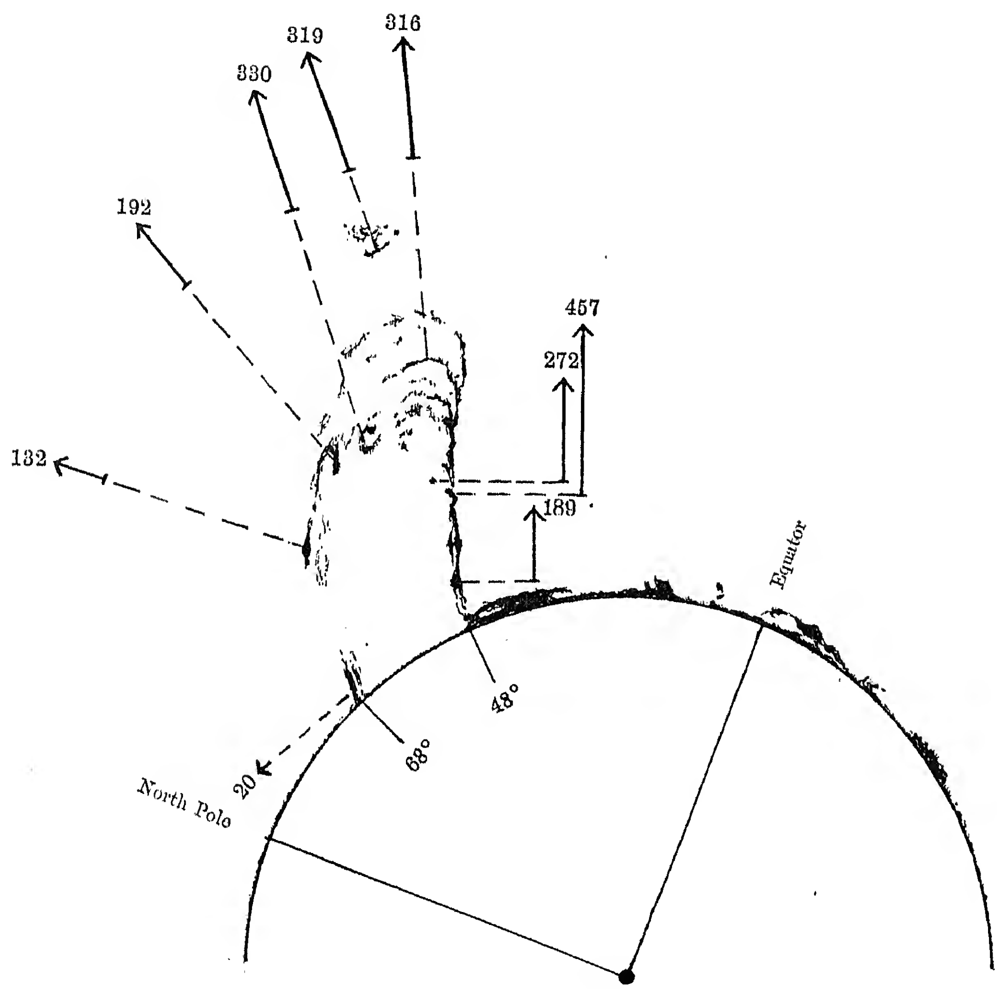


DIAGRAM SHOWING DIRECTIONS OF MOVEMENT AND VELOCITIES OF PARTS OF THE PROMINENCE IN KILOMETERS PER SECOND. THE DRAWING REPRESENTS THE PROMINENCE AT 8^h 57^m I. S. T., EXCEPTING THE HIGHEST DETACHED PORTION WHICH WAS ALL THAT REMAINED AT 9^h 22^m.

Kodaikanal Observatory.

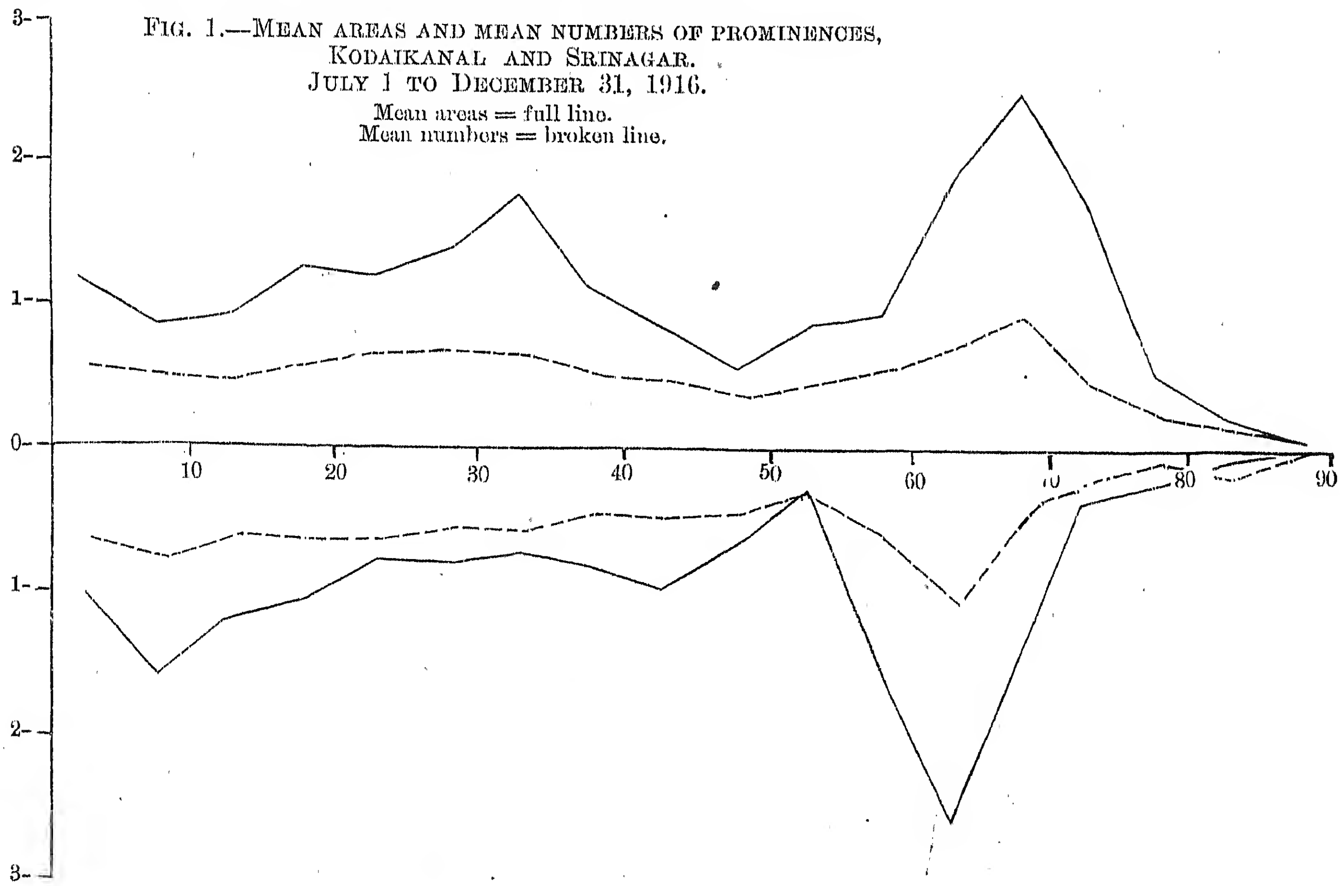
BULLETIN No. LVI.

SUMMARY OF PROMINENCE OBSERVATIONS FOR THE SECOND HALF OF THE YEAR 1916.

In this bulletin the spectroheliograms obtained at Srinagar until the end of October by the Kashmir expedition under Mr. J. Evershed, F.R.S., the Director, have been used to supplement the Kodaikanal series. Visual observations at Kodaikanal were practically confined to displacements of the hydrogen lines and to metallic prominences, as the position angles, heights, and areas can now be much more satisfactorily determined from the photographs. For those days when Kodaikanal photographs of prominences were incomplete, imperfect or wanting, the photographs taken at Srinagar were substituted when available. This inclusion of the Srinagar photographs up to the end of October raises the total number of days of observations from 163 to 169, and the number of effective days from 152 to 162.

The distribution of prominences observed and photographed during the half-year ending December 31, 1916, is represented in the accompanying diagram. The full line gives the mean daily areas and the broken line the mean daily numbers for each zone of 5° of latitude. The ordinates represent tenths of a square minute of arc for the full line and numbers for the broken line.

FIG. 1.—MEAN AREAS AND MEAN NUMBERS OF PROMINENCES, KODAIKANAL AND SRINAGAR. JULY 1 TO DECEMBER 31, 1916.
Mean areas = full line.
Mean numbers = broken line.



The noteworthy features of the distribution are the minimum near 50° and the maximum near 65°. This maximum has moved another 5° nearer to the poles compared with the previous half-year ; the northern zone is about 5° ahead of the southern, as is also clearly shown in the prominences projected on the disc as absorption markings. The maximum near 30° which has been noted for several preceding half-years has almost disappeared.

The mean daily areas and daily numbers (corrected for partial observations) are given in the table below, where the data for Kodaikanal alone are given separately for the sake of uniformity with previous bulletins.

		Mean daily areas (square minutes).	Mean daily numbers.
Kodaikanal and Srinagar observations (162 effective days).	North	1·98	9·28
	South	1·60	8·81
	Total ...	3·58	18·09
Kodaikanal observations (152 effective days.)	North	2·04	9·37
	South	1·61	8·92
	Total ...	3·65	18·29

The above figures show a decrease of 6·5 per cent in areas and of 6·2 per cent in numbers, when compared with those of the previous half-year. The distribution in latitude shows that the diminution in area affects practically all latitudes but is especially marked in the south between 20° and 40°.

There has been an excess of prominence activity in the northern hemisphere, namely 55·3 per cent in areas and 51·2 per cent in numbers. The excess of activity in the northern hemisphere is also to be seen in metallic prominences, in the displacements of the hydrogen lines in prominences and in the $H\alpha$ absorption markings.

The monthly, quarterly, and half-yearly frequencies and the mean heights and extents of prominences recorded at Kodaikanal and Srinagar are given in the following table. The frequencies are derived from the number of effective days.

Abstract for the second half of 1916.

Month.	Number of days of observations. Total.	Effective.	Number of prominences.	Mean daily frequency.	Mean height.	Mean extent.
1916.					″	°
July	30	30	433	14·4	32·3	2·51
August	30	29	489	16·9	35·6	2·46
September	26	24	415	17·3	33·0	2·34
October	29	27	479	17·7	36·7	2·46
November	27	26	566	21·8	32·1	2·54
December	27	26	547	21·0	34·5	3·32
Third quarter ...	86	83	1337	16·1	33·7	2·44
Fourth quarter ...	83	79	1592	20·2	34·3	2·78
Second half-year ...	169	162	2929	18·1	34·0	2·62

Distribution east and west of the sun's axis.

Areas show a preponderance at the western limb, and numbers at the eastern limb as shown below. The most probable excess due to chance when 2929 prominences are observed is $\pm 0{\cdot}62$ per cent, and the occurrences of 51·25 per cent and 47·90 per cent at either limb are respectively 2·5 and 13·2 times less likely than 50 per cent at each limb :—

1916 July to December.	East.	West.	Percentage east.
Numbers observed	1501	1428	51·25
Total areas in square minutes	2780	3024	47·90

Metallic prominences.

The following metallic prominences were recorded in the half-year :—

TABLE I.—LIST OF METALLIC PROMINENCES OBSERVED AT KODAIKANAL, JULY TO DECEMBER 1916.

Date.		Hour I.S.T.		Base.	Latitude.		Limb.	Height.	Remarks.
					North.	South.			
1916.		H.	M.	°	°	°		″	
July	1	8	40			12	W	15±	D_1, D_2, b_1, b_2, b_3, b_4 faint.
	5	8	26	10	22		W	90	D_1, D_2, b_1, b_2, b_3, b_4, 5316·8, 5276·2.
August	10	8	50	6		18	W	45	D_1, D_2, b_1, b_2, b_3, b_4, 5316·8, 6677.
	14	10	3	2	13		E	10	D_1, D_2, b_1, b_2 very bright.
	25	8 to 9	50 to 10	12	24		W	150	6677, D_1, D_2, 5323·1, 5316·9, 5383·8, 5276·2, 5270·6, 5269·8, b_1, b_2, b_3, b_4, 5234·9, 5227·4, 5227·0, 5208·8, 5206·2, 5204·8, 5197·8, 5018·6, 5016, 4924·1.
September	22	10	10	1	17·5		W	15	D_1, D_2, b_1, b_2, b_3, b_4.
	25	9	32		25		W	20	D_1, D_2, b_1, b_2, b_3, b_4.
November	1	8	25	5		18·5	E	65	D_1, D_2, b_1, b_2, b_3, b_4, 5316·8.
	2	8	52		20		E	20	6677.
	13	8	18	2	16		W	15	D_1, D_2, b_1, b_2, b_3, b_4.
	28	9	0			16	E	30	6677, D_1, D_2, 5363·0, 5316·8, 5276·2, 5234·8, 5197·8, b_1, b_2, b_3, b_4, 5018·6, 5016, 4924·1.
December	2	8	42			10	W	10	D_1, D_2, b_1, b_2, b_3, b_4, 5316·8 slightly bright.
	4	8	37	8	33		E	25	Whole prominence seen in D_1, D_2, b_1, b_2, b_3, b_4, 5316·8.
	6	8	35		27		W	15±	4924·1, 5016, 5018·6, b_1, b_2, b_3, b_4, 5197·8, 5234·8, 5276·2, 5284·2, 5316·8, 5363·0, D_1, D_2, 6677, 7065.
	10	8	52	4		43	W	30	D_1, D_2, b_1, b_2, b_3, b_4, 5316·8.
	10	8	58		5		W	60	Do.
	10	8	59		10		W	low	Do.
	10	8	59	2	16		W	25	D_1, D_2, b_1, b, b_3, b_4, 5316·8, 5234·8, 5276·2, 5363·0.
	17	8	38	4	35		W	30	D_1, D_2, b_1, b_2, b_3, b_4, 5316·8.
	18	8	55	4	15		W	35	Do.
	19	8	38			33	W	145	Do.
	23	8	22	3	17·5		E	40	Do.
	25	8	35	4		41	E	40	Do.
	27	8	58	6	12		E	15	Do.
	30	8	36	3	10·5		E	60	Do.

The total was 25 against 33 in the preceding half-year. Their distribution, north and south, and extreme and mean latitudes are given below :—

	Number.	Mean latitude.	Extreme latitudes.
North	17	18·7	35, 5
South	8	23·9	43, 10

Nine of these were observed on the eastern hemisphere and the remaining sixteen on the western.

Displacements of the hydrogen lines.

Particulars of the displacements observed are given in Table II.

TABLE II.—DISPLACEMENTS OF THE HYDROGEN LINES.

Date.		Hour. I.S.T.		Latitude.		Limb.	Displacement.			Remarks.
				North.	South.		Red.	Violet.	Both ways.	
1916.		H.	M.	°	°		Å	Å	Å	
July	1	8	40		12	W	Slight			
	2	8	27	32		W	Do.			At top. Height 100″ at 8^h 27^m; 75″ at 8^h 52^m and 35″ at 10^h 6^m.
	5	8	15	9		E		0·5		
	5	8	4		35	E		Slight		
	6	8	33		84·5	W		Do.		
	6	8	30		58·5	W		Do.		No prominence.
	6	8	17	85		W	Slight			
	8	8	20	21		W			Slight	Over whole prominence (70″ high).
	9	10	7		76·5	W		Slight		
	9	10	0	22		W		Do.		
	12	8	27		31·5	W	Slight			
	13	9	35		9	E		0·5		Over upper half of prominence (160″ in height).
	18	8	26	67·5		E		0·5		
	18	8	35		50	E		0·5		Over whole prominence (height 20″). Amount 1 A at 8^h 38^m. No displacement at 8^h 45^m.
	18	8	24		75	W	Slight			
	20	9	1	52·5		E		Slight		
	20	9	8	11		E	*	*	Slight	On southern half of prominence base 16°, height 75″. * slightly to red at base at +7° E and 1 A to violet over the whole prominence to the south of it at 9^h 10^m.
	20	8	56		85	E	Slight			
	20	8	48	25·5		W		Slight		
	20	8	45	35		W			Slight	No prominence.
	21	8	50	12·5		E	Slight			
	22	8	43	67·5		E		Slight		
	23	8	58		13	W			Slight	
	24	10	30	67		E	Slight			At base.
	24	10	20	23·5		W		3		Slight at 10^h 22^m. No prominence here.
	26	8	56		78·5	E	1			2 A at 8^h 59^m.
	26	8	42		9·5	W	2			At top.
	31	9	50	15		E		1		At the end of the streamer flowing north.
	31	8	58		29	E	0·5			Over whole prominence; height 40″±.
	31	9	25	10·5		W		1		Displacement gone at 9^h 27^m.
	31	9	15	16		W			2 to red and 1 to violet.	There appeared to be dark C also displaced contiguous to bright C towards violet. This feature was not visible at 9^h 27^m.

Date.		Hour I.S.T.		Latitude.		Limb.	Amount of displacement.			Remarks.
				N.	S.		Red.	Violet.	Both ways.	
1916.		H.	M.	°	°		Å	Å	Å	
August	1	9	13	19		W	1	0·5		Form but not the amount of displacement changing.
	4	8	0	12		W			Slight	No prominence.
	10	8	50		18	W		1		
	14	10	3	13		E			Slight	1 A to violet at $10^h 4^m$.
	16	9	30	9·5		E		Slight		
	21	9	17		24	E	Slight			
	21	9	10		19	W			Slight	
	23	9	4		1	W	Slight			
	23	8	59	42		W		Slight		
	24	9	5	83		E	Slight			
	24	8	55		19	E			Slight	
	24	8	55		25	E	Slight			
	24	9	12	12		W	Do.			
	25	8	35	29		W	1			Prominence at this position detached in Hα. Displacement over whole detached part. Displacements Slight at $9^h 15^m$.
	25	8	40	18		W		1		At base.
	25	9	15	24		W		2		At base.
	27	8	30		6	E	0·5			
	27	8	16		63·5	W		Slight		
	27	8	5	33·5		W		Do.		
	27	8	2	77		W		0·5		
September	2	8	55	55·5		W	Slight			No prominence.
	3	8	48	1		W			Slight	
	3	8	40	68		W	Slight			
	4	10	54	22		W		Slight		At top ; height 10″.
	6	8	48		3	E	1			
	6	8	31	10		W	0·5			Not seen at $9^h 0^m$.
	6	8	29	35		W		Slight		
	13	9	55		41·5	E	Slight			
	18	8	37		82·5	E	Do.			
	22	10	10	17·5		W		1		
	23	8	40		19·5	E		Slight		
	24	8	36	27		W	Slight			
	25	9	32	25		W	Do.			
	25	8	12	53		W		Slight		At the southern end of the streamers. Displacements over 5° on the southern side ranging from slight to 2 Å. $8^h 20^m$. Nothing at $8^h 25^m$.
	26	11	25	19		W		Slight		
	26	11	27	24		W		1·5		
	27	8	37	83		E	Slight			
	27	8	33		81	E	Do.			
	29	8	35	69		E		Slight		At top ; height 20″.
	29	8	25		36	E	Slight			
	30	9	6	33		E		1·5		
October	1	8	29	21		W	0·5			At top ; height 30″.
	2	8	40		32	E	1	Slight		Over the whole prominence ; height 15″.
	4	11	15	18		E	Slight			
	7	8	57	25		E		Slight		
	8	9	5	18		E			Slight	
	8	8	49		69·5	E		Slight		
	11	8	45		3	E	1			
	11	8	32		35	E			Slight	
	13	8	48	80·5		E	Slight			
	13	8	50	32		E	0·5			
	14	9	40		18	E		0·5		
	17	8	24	38		E	Slight			At top ; height 35″.

Date.		Hour I.S.T.		Latitude.		Limb.	Amount of displacements.			Remarks.
				N.	S.		Red.	Violet.	Both ways.	
1916.		H.	M.	°	°		Å	Å	Å	
October	17	8	15	8		W	2	Slight		To red at top and to violet at base. (Height 20″.) D_3 similarly displaced.
	17	8	8	46		W		Do.		At base.
	20	9	28	20·5		W	0·5			
	24	8	15	66·5		W	Slight	Slight		To violet at top, to red a little lower. (Height 95″.)
	24	8	31	75·5		W		0·5		
	25	8	28	35		E	Slight			
	25	8	38		19·5	W	Do.	1		
	25	8	41	12		W	0·5			
	26	8	39	58·5		W		Slight		
	27	9	9	34·5		E		Do.		Over whole prominence.
	31	8	30	63·5		E	Slight			
	31	8	35	18		E		Slight		At top.
November	1	8	30	24		E	1·5			
	1	8	25		18·5	E	Slight			At base.
	2	8	50	23·5		E			Slight	
	2	8	28	52·5		W	0·5			Over whole prominence.
	2	8	22	74·5		W	Slight	Slight		To red over the longer streamer and to violet at base of prominence.
	2	8	22	82		W		Do.		At base.
	3	8	28	26		E	1	0·5		To red at base, to violet at top.
	4	8	30	30		E		3		3 Å at top, 2 Å at base.
	4	8	23	19·5		W		1·5		
	4	8	20	Equator		E	1·5			
	5	8	41	29		E			1	
	6	10 & 9	35 & 37	7·5		E	4 at base $9^h\ 37^m$	0·5 at top $10^h\ 35^m$		
	6	9	8	57		W			Slight	At base.
	8	10	12		18	E	Slight			
	9	9	6	19		E		Slight	Slight	
	9	8	40	57		W	0·5			
	11	9	6	30		E	Slight			
	12	9	19		30	E	Do.			
	13	8	18	17		W		0·5		
	14	8	27	4		E		Slight		
	14	8	49	27·5		W		0·5		At base.
	16	9	57		83	E		Slight		
	18	8	17	20		W		Do.		
	21	8	42		22	E			Slight	
	21	8	42		24·5	E	0·5*		Do.	* To red at $8^h\ 44^m$.
	21	8	46		35	E	0·5			At base.
	21	8	17	52		W		Slight		
	26	9	52		26	E			Slight	
	27	8	45	41		E	Slight			
	27	8	28	53		W		0·5		No prominence.
	27	8	25	75		W		Slight		At base.
	27	8	23	87·5		W		Do.		Do.
	28	8	55	6·5		E	Slight			
	28	9	00		16	E	1	0·5		
	28	8	38	17		W			Slight	
	30	9	8	15·5		E		Slight		
December	1	8	57		18·5	E	1 at base.	2 at top.		
	2	8	48		40	W	0·5			
	2	8	43		18	W			Slight	
	2	8	39	25		W		Slight		
	4	8	37	33		E		0·5		At base. 1Å to violet at top at $8^h\ 43^m$. 3Å to violet at top and 0·5 Å to red at base at $8^h\ 45^m$.

Date.		Hour I.S.T.	Latitude.		Limb.	Amount of displacement.			Remarks.
			N.	S		Red.	Violet.	Both ways.	
1916.		H. M.	°	°		Å	Å	Å	
December	5	10 50	28		W	2	Slight		Slightly to violet at base at 26°·5. 10h 52m.
	5	10 45	59·5		W			Slight	No prominence.
	6	8 35	27		W	Slight	Slight		
	9	8 57		38	E	0·5			At base.
	9	8 25	65		W		Slight		On the upper part. Height 100″.
	10	8 57		8	W	0·5			
	11	8 48	9		E		Slight		
	14	8 18	88·5		E	0·5			
	14	8 32	58·5		W		0·5		
	15	8 52		17	E		1·5		
	15	8 42		48	W	0·5			
	17	8 24	20		E	Slight	Slight		To red at top, to violet on lower part. Height 60″.
	17	8 19		13	E	Do.			
	17	8 35	25		W	Do.			
	18	8 55	15		W		1·5		
	19	8 51		26	E	0·5			
	19	8 38		33	W		Slight		
	19	8 38		33	W	Slight	Do.		To violet at base, to red at top. Height 145″.
	21	8 37	47		E	0·5			
	21	8 47		11	E		Slight		
	21	8 54		19	E	0·5			
	22	8 32		20	E	1·5			
	22	8 30		26	E		Slight		
	24	8 19	88				0·5		
	24	8 22		21	W		Slight		
	25	8 46		1	E	Slight			
	26	8 40	6		E	Do.			
	27	8 54	17		E	Do.			
	27	8 55	13		E	0·5	2		Only to violet at 8h 58m and nothing at 9h 0m.
	27	9 4		66·5	E		1		At top. Height 30″.
	28	8 38	12		E	3		0·5	No prominence. Both ways lower in chromosphere and to red higher up. A prominence 25″ at 8h 41m.
	28	8 41	6·5		E	1			
	28	8 27		17·5	W	Slight			
	29	8 45	13		E		Slight		
	29	8 30	18		E		0·5		
	30	8 39	56		E	Slight			
	30	8 36	10·5		E	Do.			
	30	8 48	10		W	Do.			
	30	8 51	47·5		W	Do.			
	31	9 0		61	E	Do.			
	31	8 47	25		W		0·5		
	31	8 45	45		W		Slight		

The total number observed was 179 against 260 of the preceding half-year. There were 115 in the northern hemisphere and 63 in the southern, 1 being on the equator; 93, or 52 per cent, were in the eastern hemisphere, 85 in the western and 1 on the central meridian.

Eighty-nine of them were to the red, 87 to the violet and 23 both ways simultaneously. Between 0° and 30° there were displacements observed in 105 prominences, between 31° and 60° in 42, and between 61° and 90° in 32.

Reversals and Displacements of the C line on the Disc.

One hundred and eighty-four reversals of the C line near spots, 17 darkenings of the D_3 line, and 44 displacements were recorded. Each of these is a marked decrease on the previous half-year. Their distribution

east and west of the central meridian together with the most probable excess due to chance is given below :—

	East.	West.	Percentage east.	Most probable excess.
Reversals of C near spots	104	80	56·5	±2·5%
Darkenings of D_3	10	7	58·8	±8·4%
Displacements of C	20	22	47·6	±5·1%

There was a large preponderance of displacements towards the red, 31 being to the red, 14 to the violet, and 7 both ways simultaneously.

Prominences projected on the disc as absorption markings.

The grating spectroheliograph for photographing the absorption markings in $H\alpha$ light was in regular use during the six months. Photographs were obtained on 111 days counted as 93 effective days. The mean daily areas in millionths of the sun's visible hemisphere, corrected for foreshortening, and the mean daily numbers are given below :—

	Areas.	Numbers.
North	980·6	7·51
South	746·2	5·34
Total ...	1726·8	12·85

The areas of absorption markings given in Kodaikanal Observatory Bulletins XLVII, L, and LII, for the year 1915 and the first half of 1916 should be multiplied by 2, those given for previous years being correct. They are reproduced correctly below :—

Mean daily areas of $H\alpha$ Absorption markings.

(Millionths of the sun's visible hemisphere.)

	1915 January to June.	1915 July to December.	1916 January to June.
North	1536·4	984·0	812·2
South	1214·8	1347·8	879·8
Total ...	2751·2	2331·8	1692·0

The distribution of the absorption markings in latitude is shown in the accompanying diagram, and is similar to that in the previous half-year, except that there is a secondary minimum in the belt 25° to 30°.

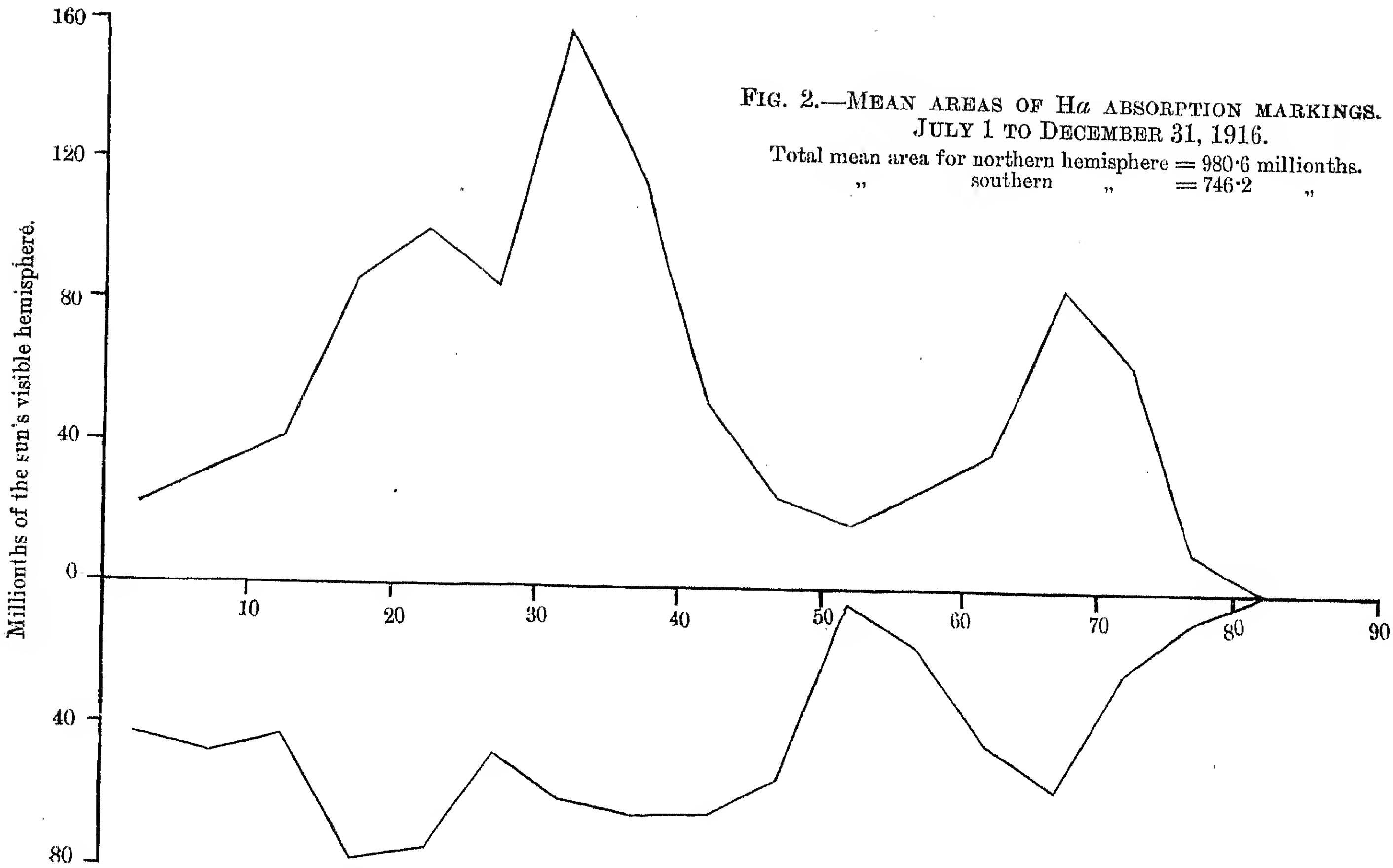


FIG. 2.—MEAN AREAS OF Hα ABSORPTION MARKINGS.
JULY 1 TO DECEMBER 31, 1916.
Total mean area for northern hemisphere = 980·6 millionths.
" southern " = 746·2 "

Contrary to every other form of prominence activity these markings show an increase on the previous half-year. The increase is, however, entirely in the northern hemisphere, both areas and numbers showing a decrease in the southern hemisphere compared with the previous half-year.

The distribution east and west of the central meridian has reverted to the usual excess on the eastern side, the percentage on the eastern side being 55·8 in areas and 54·8 in numbers. The most probable excess due to chance is 1·0 per cent on either side, whilst the chances of excesses of 5·8 per cent and 4·8 per cent *on either side* are respectively 240 and 3100 times less than that of equality on each side.

KODAIKANAL OBSERVATORY,
6th March 1917.

T. ROYDS,
Assistant Director.

PRICE, 8 *annas*.]

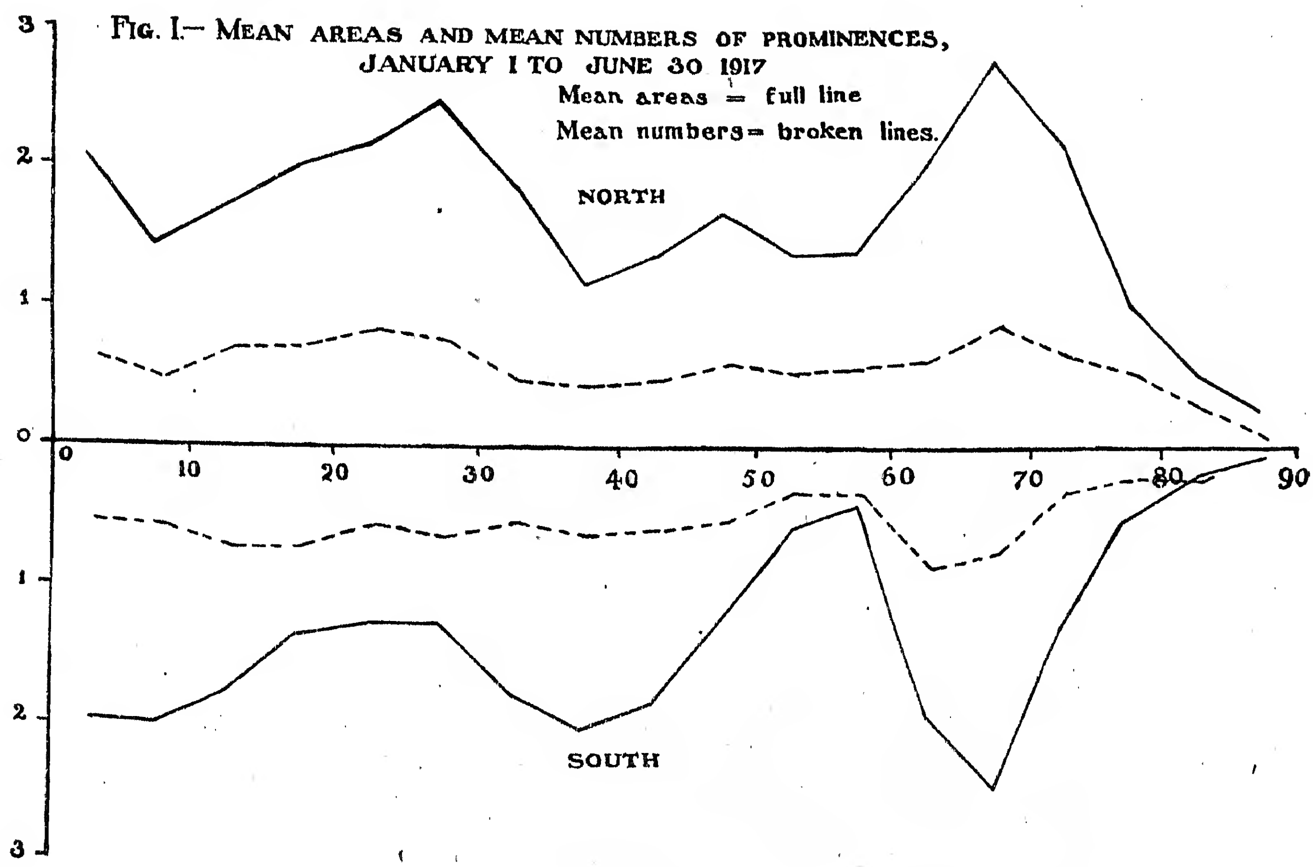
Kodaikanal Observatory.

BULLETIN No. LVII.

SUMMARY OF PROMINENCE OBSERVATIONS FOR THE FIRST HALF OF THE YEAR 1917.

The summary given in this bulletin is based on observations made at Kodaikanal only. Visual observations were practically confined to displacements of the hydrogen lines and to metallic prominences, as the position angles, heights and areas can now be much more satisfactorily determined from the photographs.

The distribution of prominences observed and photographed during the half-year ending June 30, 1917, is represented in the accompanying diagram. The full line gives the mean daily areas and the broken line the mean daily numbers for each zone of 5° of latitude. The ordinates represent tenths of a square minute of arc for the full line and numbers for the broken line. The means are corrected for incomplete or imperfect observations, the total of 164 observing days being reduced to 148 effective days.



The greatest activity is shown in the belt 65° to 70° both north and south of the equator, the southern maximum having advanced 5° towards the pole compared with the preceding half-year. Besides the marked activity near the equator there is another maximum at 25° to 30° in the northern hemisphere and at 35° to 40° in the southern.

The mean daily areas and daily numbers, corrected for partial observations, are given below :—

	Mean daily areas (square minutes).	Mean daily numbers.
North	2·94	10·32
South	2·42	9·33
Total ...	5·36	19·65

The mean daily areas show a large increase, 46·9 per cent, on the preceding half-year, and mean daily numbers an increase of 6·9 per cent. The above mean daily area is the largest recorded since 1908, although closely approached in 1915.

There has again been an excess of activity in the northern hemisphere, namely 54·9 per cent of areas and 52·5 per cent of numbers. In the region 35° to 45° there is, however, an excess in the south. An excess in the northern hemisphere is also found for metallic prominences, displacements of the hydrogen lines in prominences and for the Hα absorption markings.

The monthly, quarterly and half-yearly frequencies, and the mean heights and extents of prominences are given in the following table. The frequencies are derived from the number of effective days. Compared with the previous half-year there is a large increase in the mean extent of a prominence.

Abstract for the first half of 1917.

Month.	Number of days of observations.		Number of prominences.	Mean daily frequency.	Mean height.	Mean extent.
	Total.	Effective.				
1917.					″	°
January	25	22	416	18·9	38·5	3·37
February ...	26	25	525	21·0	37·6	4·25
March	30	28	577	20·6	39·8	3·37
April	30	27	541	20·0	40·4	3·73
May	30	29	565	19·5	37·1	3·83
June	23	17	285	16·8	38·1	3·87
First quarter ...	81	75	1518	20·2	38·7	3·67
Second quarter ..	83	73	1391	19·1	38·6	3·80
First half-year ..	164	148	2909	19·7	38·6	3·73

Distribution east and west of the sun's axis.

Areas show a slight preponderance at the eastern limb, whereas numbers show practically no excess, as is seen below. When 2908 prominences are observed the most probable excess due to chance is ± 0·62 per cent, so that the preponderance of areas observed may very well be due to chance only.

1917 January to June.	East.	West.	Percentage east.
Number observed	1455	1454	50·02
Total areas in square minutes	4035	3897	50·87

Metallic prominences.

The following metallic prominences were recorded in the half-year :—

TABLE I.—LIST OF METALLIC PROMINENCES OBSERVED AT KODAIKANAL, JANUARY TO JUNE 1917.

Date.		Hour I.S.T.		Base.	Latitude.		Limb.	Height.	Lines.
					North.	South.			
1917.		H.	M.	°	°	°		″	
January	17	10	26	1		11·5	E	65	4924·1, 5016, 5018·6, b_1, b_2, b_3, b_4, 5197·8, 5276·2, 5283·7, 5316·8, 5328·2, 5371·8, 5397·2, 5404·3, 5405·9, 5429·9, 5434·7, 5447·1, 5455·7, 5535·0, D_1, D_2, 6677—all very bright.
	23	8	30		15		E	90	b_1, b_2, b_3, b_4, 5316·8.
	25	8	49	13	14·5		E	270	b_1, b_2 bright at base from $+8°$ to $+21°$.
	28	8	44	11		22·5	W	20	6677, D_1, D_2, 5316·8, 5197·8, b_1, b_2, b_3, b_4, 5018·6, 5016 (slightly), 4924·1.
February	16	9	13	67		17·5	W	150	D_1, D_2, b_1, b_2, b_3, b_4, 6677, 7065, 5316·8, 4924·1, 5016.
	18	8	50			17	W	80	b_1, b_2, b_3, b_4, 5316·8.
	22	8	41	5	30		E	45	D_1, D_2, b_1, b_2, b_3, b_4.
	26	9	0	1	28·5		E	15	D_1, D_2, b_1, b_2, b_3, b_4, 5316·8.
March	2	9	3			20	E	120	D_1, D_2, b_1, b_2, b_3, b_4, 6677, 7065, 5161·8.
	8	8	50		27		W	20	6677, D_1, D_2, 5316·8, 5234·8, 5197·6, b_1, b_2, b_3, b_4, 5018·6, 5016, 4924·1.
	9	8	50		20		E	15	D_1, D_2, b_1, b_2, b_3, b_4, 5316·8, 5766.
	11	8	50	5	27·5		W	50	7065, 6677, D_1, D_2, 5383·6, 5316·8, 5276·2, 5234·8, 5197·6, b_1, b_2, b_3, b_4, 5018·6, 5016, 4924·1—all very bright.
	15	8	48	4		11	W	60	D_1, D_2, b_1, b_2, b_3, b_4.
	19	8	53	14	13		E	180	D_1, D_2, b_1, b_2, b_3, b_4, 6677.
	20	9	4	3	25·5		E	65	D_1, D_2, b_1, b_2, b_3, b_4.
	27	8	43	6	20		E	20	D_1, D_2, b_1, b_2, b_3, b_4.
	27	8	48			23	W	30	4924·1, 5016, 5018·6, b_1, b_2, b_3, b_4, 5197·8, 5276·2, 5316·8, D_1, D_2.
April	4	8	57	2	29		W	30	D_1, D_2 slightly bright.
	5	8	45	2	13		W	90	7065, 6677, D_1, D_2, 5316·8, 5284·3, 5276·2, 5234·8, 5197·8, b_1, b_2, b_3, b_4, 5018·6, 5016, 4924·1—all very bright.
	16	8	57	5	25·5		E	120	Whole prominence visible in D_1, D_2, b_1, b_2, b_3.
	22	8	32	4		16	W	90	4924·1, 5016, 5018·6, b_1, b_2, b_3, b_4, 5197·7, 5234·8, 5276·2, 5284·3, 5316·8, D_1, D_2, 6677.
May	4	9	5	5	22·5		W	20	D_1, D_2, b_1, b_2, b_3.
	8	8	45	4		24	W	60	4924·1, 5016, 5018·6, b_1, b_2, b_3, b_4, 5197·7, 5234·8, 5276·2, 5284·2, 5316·8, D_1, D_2, 6677, 7065.
	9	8	37	7	18·5		E	40	D_1, D_2, b_1, b_2, b_3.
	12	9	5	25	22·5		E	115	D_1, D_2, b_1, b_2, b_3, 6677, 7065.
	22	8	35	3		25·5	E	30	6677, D_1, D_2, b_1, b_2, b_3, b_4, 5316·8.
	24	8	59	2		5	E	25	6677, D_1, D_2, b_1, b_2, b_3, b_4, 5316·8.
	26	8	44			23	E	15	6677, D_1, D_2, 5316·8, b_1, b_2, b_3, b_4, 5018·6, 5016, 4924·1.
	26	8	55	2		15	W	90	6677, D_1, D_2, 5535·05, 5363·0, 5316·8, 5283·2, 5276·2, 5234·8, 5197·5, b_1, b_2, b_3, b_4, 5018·6, 5016, 4924·1.
	28	9	5		10		W	20	D_1, D_2, b_1, b_2, b_3, b_4, 5316·8, 6677.
June	3	8	59	7	17·5		W	65	D_1, D_2, b_1, b_2, b_3, b_4, 5316·8, 4924·1, 5234·8, 5016, 6677.
	22	8	53		22		W	10	D_1, D_2, b_1, b_2, b_3, b_4.

The total was 32 against 25 in the preceding half-year. Their distribution north and south, and extreme and mean latitudes are given below. They were equally divided between the eastern and western limbs.

	Number.	Mean latitude.	Extreme latitudes.
		°	
North	19	21·1	30,° 10°
South	13	17·7	25·5, 5

Displacements of the hydrogen lines.

Particulars of the displacements observed are given in Table II.

TABLE II.—DISPLACEMENTS OF THE HYDROGEN LINES.

Date.		Hour I.S.T.		Latitude.		Limb.	Displacement.			Remarks.
				North.	South.		Red.	Violet.	Both ways.	
1917.		H.	M.	°	°		Å	Å	Å	
January	4	8	55		26·5	E	Slight			No prominence.
	4	8	59		45·0	E			Slight	Do.
	4	8	30	41·5		W	1			Near base.
	5	10	41	20		W	Slight			At top.
	6	8	53		52	E	Do.			
	6	8	29	9·5		W		1		
	6	8	23	64		W	Slight			
	12	10	48	17·5		W	0·5			
	14	8	28	23		W	Slight			
	16	8	30	48·5		W		Slight		About the middle of the prominence.
	17	10	26		11·5	E	Slight			
	18	10	28	32·5		E	Do.			
	18	9	38		85	—	1			On upper half.
	19	8	52	26		W		Slight		
	19	8	52	28		W	Slight			
	20	8	45		82	W	Do.			
	20	8	35		77	W		Slight		
	20	8	32		49·5	W	Slight			
	21	8	38	11		E	Do.			
	23	8	30	15		E	0·5	Slight		2 A to red a little to the south of it.
	23	8	19	17		W		Do.		
	23	8	18	35		W		2		
	24	8	29	16		E	1·5	1·5		
	25	8	43		1	E		Slight		
	25	9	5	78		W	Slight			
	26	8	36	13·5		E		1		At several places.
	27	8	48	40		E	Slight			At base.
	27	9	20	40		E		Slight		Do.
	27	8	55		20	E	Slight			
	28	8	20		83·5	W	Do.			
	28	8	40		43·5	W		Slight		
	28	8	44		20	W			0·5	
	29	9	2	2		E	Slight			
	29	9	7	2		E		0·5		
	29	8	41	64		W	Slight			Over the whole prominence.
	29	8	39	78		W	Do.			
	30	8	53	29		E	Do.			
February	2	15	20	13		E			Slight	No prominence.
	3	11	11		15	E			0·5	Do.
	3	11	11		16	E		0·5		Do.
	4	8	41	12		E	0·5			
	4	8	47		23	E	Slight			
	4	8	20	68		W	Do.			Near base.
	5	9	15	26		E		0·5		Over the whole prominence.
	5	9	4	Equator		E	Slight			
	7	8	50	33		W	0·5			At top.
	7	8	46	55		W	0·5			At top of the lower prominence.
	11	8	29	76·5		E	0·5			No prominence.

Date.	Hour I.S.T.	Latitude. North.	Latitude. South.	Limb.	Displacement. Red.	Displacement. Violet.	Displacement. Both ways.	Remarks.
1917.	H. M.	°	°		Å	Å	Å	
February 11	8 58		29	E	0·5			
11	8 31	73·5		W	Slight			At top.
12	8 43	83·5		—	0·5			No prominence.
12	8 35	66·5		E	Slight			
12	9 11	1		W			Slight	
12	8 53	16		W			Do.	
13	11 45	60·5		W	Slight 1·0			
14	9 9	44		E	0·5			
14	9 15		30	E		Slight		At top.
14	8 57		9	W	0·5			
14	8 44	52		W	Slight			At top.
14	8 38	73		W	1			Do.
16	8 50	83		—		Slight		
16	8 45	72		E	0·5			
16	9 4		10·5	W	Slight			C displaced 0·5 A both ways at —13°.5 West near base. Higher up, C was displaced to red by different amounts—maximum being 6 A at 9^h 4^m. Displacement 0·5 A both ways at base and 0·5 A to violet higher up at 10^h 20^m. At 9^h 4^m there was a faint patch of light at more than 7 A. A similar patch—probably a ghost—was seen on the other side also. At —19° West C was displaced at several points to red, the greatest amount being 3 A at 9^h 15^m.
16	8 59	31		W	Slight			
16	8 55	64·5		W		Slight		At several places.
18	8 35	7		E		0·5		
18	8 50		17	W		0·5		
22	8 35	12·5		E		Slight		At top.
22	8 32		15	E	Slight			
22	8 30		41·5	E	Do.			
25	8 51		81·5	E	Do.			
25	8 41		38	W		Slight		
25	8 36	27		W	Slight			
27	9 6	64		E		Slight		
27	8 45		3	E	Slight			
27	8 43		16	E	Do.			At top.
27	8 54		23	W		0·5		
27	8 55		13·5	W	0·5	Slight		
28	9 0		16	W		2		At base.
March 1	9 14		12	E	1	0·5		Over jets.
1	9 17		18·5	E	1			Not seen at 9^h 25^m.
1	9 0		23	W		2		
2	8 52		20	E	1			At base.
2	9 3		20	E		1·5		At top.
3	9 1	49·5		W			Slight	
4	8 40	41·5		E		Slight		Near base.
4	8 41	30		E	0·5			At top.
5	8 53	22		E		1		
6	8 48	28		W	0·5			At top. Not seen at 9^h 2^m.
9	8 50	20		E	Slight			At base.
10	9 5	81·5		E	Do.			Do.
10	8 48		3	E	0·5			
10	8 46		20	E	Slight			
10	9 0		54·5	W	0·5			At top. Prominence and displacement disappeared at 9^h 15^m.
11	8 50	27·5		W	0·5			At top.
12	9 2		11	E	Slight			
13	8 51	13		E		Slight		
13	8 49		15·5	E	0·5			
15	8 53		19·5	W		0·5		At top.
15	8 48		11	W	Slight			Do.
15	8 46	15		W			Slight	
16	9 0		28	E	1·5			
17	8 34		30	W		Slight		At top.

Date.		Hour I.S.T.		Latitude.		Limb.	Displacement.			Remarks.
				North.	South.		Red.	Violet.	Both ways.	
1917.		H.	M.	°	°		Å	Å	Å	
March	18	9	40	12·5		W		Slight		
	18	9	33	83		W		0·5		
	19	8	53	13		E		1		At top.
	20	8	59	27		E	Slight			
	20	9	4	25·5		E	0·5			At base.
	20	8	55	7·5		W	Slight			
	20	8	49	70		W	Do.			At top.
	23	9 0 to 9 6		16·5		E	1·5	2·5		At different places.
	24	9	30	39·5		E	Slight	Slight		To red at top, to violet at base.
	27	8	35		30	E		Do.		At top.
	27	8	32		68	E	Slight			
	27	8	48		23	W			Slight	
	29	8	59	10		E	Slight			At base.
	29	9	0	6		E		Slight		
	29	8	43	58·5		W		Do		
	29	8	40	80·5		W	Slight			
	30	8	45	21		E		0·5		
	30	8	48		26	E	Slight			
	30	8	40		30	W		Slight		At base.
April	4	8	50	68		W	Slight			
	4	8	48	83		W	Do.			
	7	8	28	27		E		Slight		At base.
	8	8	16		76·5	E	Slight			
	8	8	15		82	W	Do.			
	9	8	39	15		W	0·5			
	10	8	59	16		E	Slight			
	10	8	59	13		E	0·5			
	10	8	59	11		E		1		
	12	8	39		10	E			Slight	
	12	8	39		13·5	E			Do.	
	12	8	47		83·5	E	Slight			No prominence.
	12	8	25		22	W	Do.			
	13	8	40	7		E	0·5			
	13	8	51		26	E			Slight	
	15	9	47		13	E	Slight			
	16	8	57	25·5		E		0·5 to 2		Over the whole prominence except near base, amount varying from 0·5 A to 2 A.
	16	8	48	83·5		W			Slight	
	18	8	28	28		E	Slight	Slight		To red at top, to violet at base.
	19	8	42	26·5		E	Do.			At base.
	20	8	33	26		E		0·5		Do.
	20	8	41	18		W	Slight			
	21	8	14	31		E		Slight		
	23	8	45		11	E			Slight	
	23	8	33	10		W		Slight		No prominence.
	23	8	33	15		W		0·5		
	24	8	32	11		W		0·5		At base.
	25	8	18	83·5		E	Slight			No prominence.
	25	8	42		14	E	Do.			
	25	8	29		30	W	Do.			
	25	8	24	38·5		W	0·5			At top.
	25	8	21	62·5		W	Slight			No prominence.
	25	8	19	80		W	Do.			Do.
	25	8	19	83·5		W	Do.			Do.
	26	8	40		27	E	1			
	26	8	12		77	E		0·5		
	26	9	0		25	W		1·5		
	28	9	45		60·5	E		Slight		
May	2	9	3		81	W		1		
	4	9	5	22·5		W			3	
	5	9	25	26·5		E		4		
	5	9	35		71	E		2		On the floating mass.
	5	9	14	33		W		Slight		
	7	9	5	23		E	Slight			

Date.		Hour I.S.T.		Latitude.		Limb.	Displacement.			Remarks.
				North.	South.		Red.	Violet.	Both ways.	
1917.		H.	M.	°	°		Å	Å	Å	
May	8	8	45		24	W	Slight			
	9	8	50		31	W	Do.			
	9	8	37	20		W			0·5	
	10	8	5	16·5		W	Slight			
	11	8	48	10		W	Do.			
	11	8	42		15	W	Do.			Over the whole prominence.
	12	9	5	18		E	4	8		Displacements disappeared at 9h 9m.
	13	8	37		74	E	Slight			
	15	9	10	37		E	1			
	15	8	48	39		W			Slight	No prominence.
	16	8	47		9	W		Slight		
	19	8	47		9	W		Do.		
	19	8	43	47·5		W		Do.		
	19	8	42	51		W	Slight			
	20	8	44	23		E	Do.			Over upper half.
	20	8	40		46	E		Slight		
	22	8	35		25	E	1			
	24	8	57	10		E		2		At top.
	24	8	59	1		E			Slight	
	27	9	31		15	W			Do.	
	27	9	30	7		W		Slight		
	28	9	5	10		E		1·5		
June	2	8	40	27·5		E		Slight		At top.
	2	8	36		50	E			Slight	
	3	8	59	17·5		W	2			
	8	11	50	26		E		1		
	9	15	35	6		E	1	2		At the north end of the prominence.
	11	10	2	39		E	1	1		Do.
	11	10	10		20	E			Slight	At the south end.
	13	9	8		35	W	Slight			
	16	8	50	22·5		E		Slight		
	21	8	40	32·5		E	0·5			
	22	8	58		17	W	0·5			
	22	8	53	22		W	1			
	22	8	43	75		W		Slight		At base.
	24	8	48	63·5		E		Do.		No prominence.
	29	9	0		15	W		0·5		
	30	8	16		5	E		Slight		
	30	8	19		15	E		1		Slightly changing.
	30	8	23		68	W	Slight			No prominence.
	30	8	6		6	W		Slight		At the south end of the prominence.

The total number observed was 207, against 179 in the preceding half-year. There were 122 in the northern hemisphere and 84 in the southern, 1 being on the equator ; 108 or 52 per cent were on the eastern limb, 96 on the western and 3 on the central meridian. One hundred and seventeen were to the red, 79 to the violet and 21 both ways simultaneously.

Between 0° and 30° there were displacements observed in 129 prominences, between 31° and 60° in 36, between 61° and 90° in 42.

Reversals and displacements of the C line on the disc.

Two hundred and forty-four reversals of the C line on the disc, 22 dark markings of the D_3 line, and 73 displacements were recorded, each of which is an increase on the previous half-year. Their distribution east and west of the central meridian together with the most probable excess due to chance is given below :—

	East.	West.	Percentage east.	Most probable excess.
Reversals of C near spots	126	118	51·6	± 2·2%
Darkenings of D_3	13	9	59·1	± 7·4%
Displacements of C	39	34	53·4	± 4·7%

There was a large preponderance of displacements towards the red, 46 being to the red, 20 to the violet and 7 both ways simultaneously.

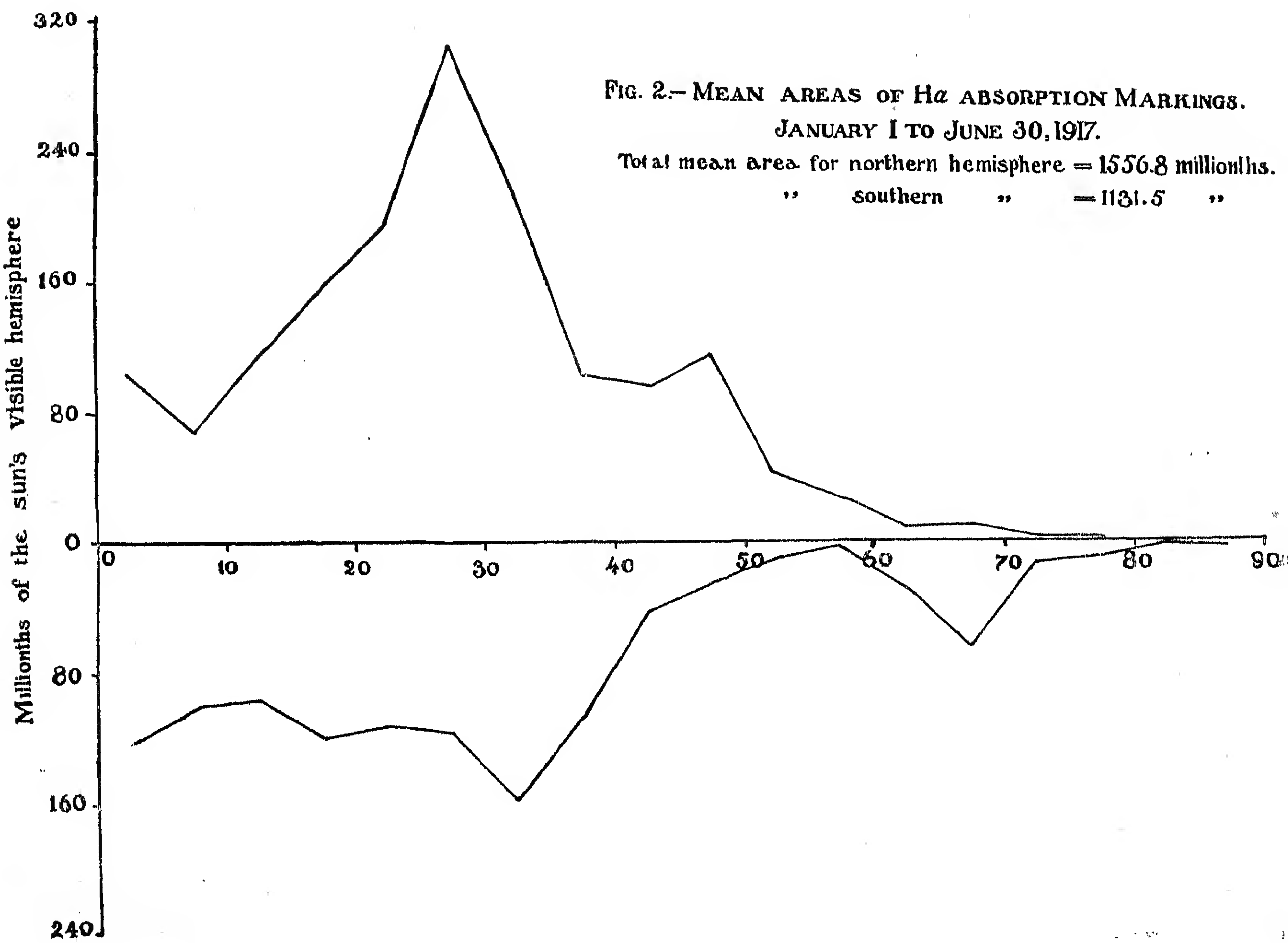
Prominences projected on the disc as absorption markings.

The grating spectroheliograph for photographing the absorption markings in Hα light was in regular use during the half-year. Photographs were obtained on 138 days counted as 125 effective days. The mean daily areas in millionths of the sun's visible hemisphere, corrected for foreshortening and the mean daily numbers are given below :—

	Areas.	Numbers
North	1556	10·14
South	1131	8·22
Total ...	2687	18·36

Compared with the previous half-year there is an increase of 55·6 per cent in areas and of 42·9 per cent in numbers. This increase is evident in the region from 0° to 50° both north and south of the equator, whilst the activity in the polar regions has entirely disappeared in the northern hemisphere, but remained unchanged in the southern.

The distribution of the absorption markings in latitude is shown in the accompanying diagram ; the only remarkable feature is the disappearance of the usually marked activity round the north pole although evident in prominences.



The distribution relative to the central meridian of the sun shows the usual excess on the eastern side, there being 52·9 per cent of areas in the eastern and 53·4 per cent of numbers. The most probable excess due to chance is 0·70 per cent on either side, whilst the chances of excesses of 2·9 per cent and of 3·4 per cent on either side are respectively 48 times and 206 times less likely than equality on both sides.

KODAIKANAL OBSERVATORY,
3rd August 1917.

T. ROYDS,
Assistant Director.

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Kodaikanal Observatory.

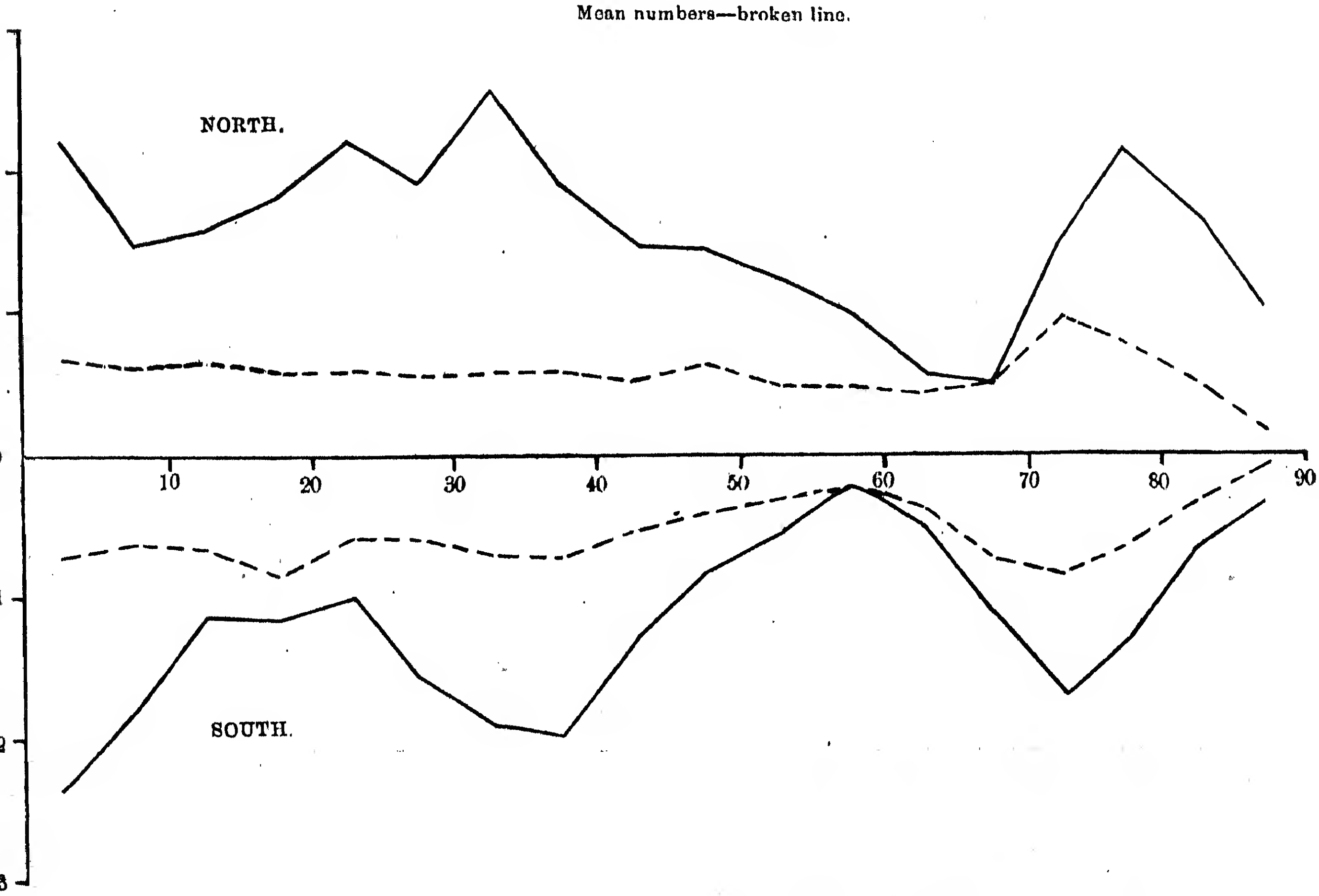
BULLETIN No. LVIII.

SUMMARY OF PROMINENCE OBSERVATIONS FOR THE SECOND HALF OF THE YEAR 1917.

The distribution of the prominences photographed at Kodaikanal during the half-year ending December 31, 1917, is represented in the accompanying diagram. The full line gives the mean daily areas and the broken line the mean daily numbers for each zone of 5° of latitude. The ordinates represent tenths of a square minute of arc for the full line and numbers for the broken line. The means are corrected for incomplete or imperfect photographs, the total of 157 days being reduced to 129 effective days.

MEAN AREAS AND MEAN NUMBERS OF PROMINENCES.
JULY 1 TO DECEMBER 31, 1917.

Mean areas—full line
Mean numbers—broken line.



The diagram indicates three principal zones of activity, a well defined zone exactly coinciding with the equator, a mid-latitude zone with maxima between $\pm 30^\circ$ and 40°, and a high latitude zone with maxima between $\pm 70^\circ$ and 80°. This distribution is very similar to that recorded for the first half of the year, excepting that the high latitude zones have advanced in latitude to the near neighbourhood of the poles. The northern zone is shown to be 5° ahead of the southern in this movement and its position is practically that which is associated with sunspot maximum.

The mean daily areas and daily numbers corrected for imperfect records are given below :—

	Mean daily areas (square minutes).	Mean daily numbers.
North	2·83	10·28
South	2·12	9·70
Total ...	4·95	19·98

The mean total area is less than that recorded for the previous half-year by about 8 per cent, although the mean number has slightly increased.

The northern hemisphere has continued more active than the southern.

The monthly, quarterly, and half-yearly frequencies, and the mean height and extent of prominences are given in the following table. The frequencies are derived from the number of effective days.

TABLE I.—ABSTRACT FOR THE SECOND HALF OF 1917.

Month.	Number of days of observations. Total.	Effective.	Number of prominences.	Mean daily frequency.	Mean height.	Mean extent.
1917.					″	°
July	28	20	355	17·8	34·5	3·90
August ...	30	22	440	20·0	39·2	4·13
September	25	20	391	19·6	35·1	2·89
October	24	21	468	22·3	38·9	2·99
November . ..	22	19	403	21·2	38·4	3·57
December	28	27	520	19·3	38·2	3·94
Third quarter ...	83	62	1186	19·1	36·4	3·65
Fourth quarter	74	67	1391	20·8	38·5	3·51
Second half-year ..	157	129	2577	20·0	37·5	3·58

The means differ but little from those found for the first half of the year, but the mean height and mean extent of the prominences have slightly diminished.

Distribution east and west of the sun's axis.

Both areas and numbers show an excess on the west limb as is seen in the table below :—

1917 July to December.	East.	West.	Percentage east.
Number observed	1258	1319	48·82
Total areas in square minutes	3070	3310	48·12

Metallic prominences.

The following metallic prominences were recorded in the half-year :—

TABLE II.—LIST OF METALLIC PROMINENCES OBSERVED AT KODAIKANAL, JULY TO DECEMBER 1917.

Date.		Hour I.S.T.		Base.	Latitude.		Limb.	Height.	Lines.
					North.	South.			
1917.		H.	M.	°	°	°		"	
July	6	8	35	5	20·5		W	50	D_1, D_2, b_1, b_2, b_3, 5316·8, 6677.
September	16	8	47	5	39.		W	40	D_1, D_2, b_1, b_2, b_3, b_4, 5316·8.
..	17	9	10		18		E	125	D_1, D_2, b_1, b_2, b_3, b_4, 6677.
October	9	8	45			16	W	120	D_1, D_2, b_1, b_2.
	24	8	31	5		17·5	W	40	D_1, D_2, b_1, b_2, b_3, b_4, 5316·8, 6677, the last line slightly.
November	3	8	45	2	Equator.		W	25	D_1, D_2, b_1, b_2, b_3, b_4.
	23	8	50		24		W	140	D_1, D_2, b_1, b_2, b_3, b_4, 5316·8.
	30	8	57		23		W	10	D_1, D_2, b_1, b_2, b_3, b_4, 5316·8, 6677.
December	2	8	28	4	23		W	30	7065, 6677, D_1, D_2, b_1, b_2, b_3, b_4, 4924·1, 5016, 5018·6, 5197·2, 5234·8, 5276·2, 5284·3, 5316·8, 5326·2, 5328·1, 5363·0, 5397·3, 5404·4, 5405·9, 5425·4, 5429·9, 5447·1, 5535·1.
	5	8	24	3	31·5		W	40	D_1, D_2, b_1, b_2, b_3, b_4.
	18	8	45	17	1·5		W	35	4924·1, 5018·6, b_1, b_2, b_3, b_4, 5197·7, 5234·8, 5276·2, 5284·2, 5316·8, 5363·0, D_1, D_2, 6677.
	19	15	49		4		W	30	D_1, D_2, b_1, b_2, b_3, b_4, 6677.
	24	8	56			9	E	120	D_1, D_2, b_1, b_2, b_3, b_4, 5316·8.
	25	8	53	13	12·5		W	75	4924·1, b_1, b_2, b_3, b_4, 5197·7, 5234·8, 5316·8, D_1, D_2, 6677.
	26	8	53	16		21	W	55	D_1, D_2, b_1, b_2, b_3, b_4, 6677.
	27	8	55	15	14·5		E	30	D_1, D_2, b_1, b_2, b_3, b_4, 5316·8, 6677.
	27	9	3	3		14·5	W	100	4924·1, 5016, 5018·6, b_1, b_2, b_3, b_4, 5197·7, 5234·8, 5276·2, 5316·8, D_1, D_2, 6677.
	29	9	4	9	24·5		W	100	4924·1, 5016, 5018·6, b_1, b_2, b_3, b_4, 5276·2, 5284·2, 5316·8, D_1, D_2, 6677, 7065.
	31	9	4	3	18·5		W	90	4924·1, 5016, 5018·6, b_1, b_2, b_2, b_4, 5197·7, 5234·8, 5276·2, 5284·2, 5316·8, 5363·0, 5535·06, D_1, D_2, 6677.

The nineteen metallic prominences recorded were distributed in latitude as shown below :—

—	Number.	Mean latitude.	Extreme latitudes.	
		°	°	°
North	13	19·6	39,	1·5
South	5	15·6	21,	9
Equator	1	...	...	

The number recorded is small considering the general activity of the sun, but this is partly explained by the unfavourable observing conditions. It may be noted that more than half the total number were observed in the month of December which was also a magnetically active month, a "great" storm being recorded by the Observatory magnetographs from the 16th to the 24th inclusive and "moderate" storms were recorded on six days.

Displacements of the hydrogen lines.

Particulars of the displacements observed in the prominences or chromosphere are given in Table III.

TABLE III.—DISPLACEMENTS OF THE HYDROGEN LINES.

Date.	Hour I.S.T.		Latitude.		Limb.	Displacement.			Remarks.
			North.	South.		Red.	Violet.	Both ways.	
1917.	H.	M.	°	°		A	A	A	
July 1	8	10		23	E		1		
2	10	12	9		W	1			
	9	44	76		W	Slight			No prominence.
4	9	12	0·5		E			Slight	
	9	16		80·5	E		Slight		
5	10	10		9·5	W	0·5			
6	8	56	29		E	0·5			Over whole prominence except near base.
	8	35	20		W	1	3		Metallic.
	8	37	17		W	3			
8	8	49		24	E		1		On upper part.
16	9	7		80	E	Slight			No prominence.
	9	7		83·5	E	Do.			Do.
18	8	57	6·5		W	0·5			Over long cloudlet at top.
19	8	45		30	E	Slight			At base.
	8	40		68·5	E	Do.			
20	9	33	64·5		E		0·5		
	9	43	8		E			0·5	
	9	45		15	E		Slight		
24	9	58	38		E		0·5		Over the whole prominence.
August 1	9	7	26		E		1		
	9	16		74	E		2		At top at north end.
	8	35	6		W		Slight		At north end.
2	8	55	10		W	0·5			
3	8	55	30		E	Slight			At top.
	8	44		16	W	0·5			
5	9	4	7		E	Slight			
	8	48	17		W	0·5			
6	8	40		17	E	2·5			
8	9	4		19	E			2	
9	8	35		14	E	Slight			
10	9	15		11	E	2	1		Displacement towards violet at base and towards red over the rest of the prominence.
	9	17		11	E	3			
10	8	55		64·5	W		Slight		
19	8	47	14		W		1		
	8	50	12		W	2	Slight		
	8	47	16·5		W	4	3		
21	9	48		20	W	Slight			
26	8	49	58·5		W		Slight		
	8	44	82·5		W		1		At base.
28	11	8	30		E		0·5		
	11	5		3	E	1·5	0·5		
	10	56		16	W	Slight			
29	9	36	28		E		0·5		
	9	40		8·5	E		2	1	To violet at south end; both ways over southern half of the prominence.
	9	55		35·5	E		Slight		
30	9	50		3	E	3			
	9	50	3 to	3	E	2			
31	9	40		20	E	2	1		Red and violet at different places.
	9	46	54·5		W	Slight			
September 8	9	25	75		E		0·5		At top.
	9	10		8	W	Slight			
9	8	31	10		W		Slight		
11	9	2		3	W		0·5		At top.
	8	47	62		W		Slight		No prominence.
12	8	55	24		E	Slight			Do.
14	9	51	21		E		0·5		At top. Not seen at $9^h 56^m$.

Date.	Hour I.S.T.	Latitude. North.	Latitude. South.	Limb.	Displacement. Red.	Displacement. Violet.	Displacement. Both ways.	Remarks.
1917.	H. M.	°	°		A	A	A	
September 14 —*continued.*	9 53		63	E		0·5		
	9 26		19	W	0·5			
	9 16	31		W		1		
	9 14	36		W	Slight			At top.
16	8 38		13	E	Do.			
17	9 10	12		E			Slight	
	9 10	18		E			1	Ghosts at a distance of 6 A on both sides of "C."
	9 11	15		E	0·5			
	8 52	23		W	Slight			
	9 0	71		W		Slight		At base.
19	9 5		69	E	0·5			
	9 2		70·5	W		Slight		At base.
20	9 4		18	E	Slight			At top.
22	8 45		16	E	Do.			
28	11 19		15	W	2	2		Red and violet displacements at different places.
October 2	14 16		3	W	Slight			
	14 3	14		W		Slight		At base.
3	8 52	33		E	Slight			
5	8 59	8		E		Slight		
6	8 38		83·5	E	Slight			
7	8 39		6	W		Slight		
8	9 4		25	W	0·5			At top.
	9 8		12	W	1·5			Do.
	9 10	1		W	1·0			Do.
9	9 3	28·5		E		0·5		
	9 5	4		E	1·5			At base.
	9 8		13	E		Slight		
	9 11		41·5	E	1			No prominence.
	8 45		16	W	0·5	0·5		Red and violet displacements at different places.
	8 42		1·5	W		Slight		
10	8 27	23·5		E		Do.		
	8 39		24	W		0·5		
13	10 1	36		E	5			At top.
15	8 29	54·5		E	Slight			
	9 41	2		E	0·5	0·5		To red at base : to violet at top.
	9 49		14	E	1·5	0·5		
	9 7		17	W	1			
16	9 0		25	E		0·5		Over streaks.
	8 45		77	W			Slight	
23	8 42		24·5	E	Slight.			Over streaks.
24	8 27	12·5		W		Slight		
26	10 50	82·5		W	Slight			
29	9 8	23		E	Do.			
	9 9	17		E		Slight		
	9 9	11		E	0·5			At base.
	9 12		0·5	E	Slight			
	8 48	18		W	1·5			
31	8 41		6·5	E	Slight			At base.
	8 34		47·5	E	Do.			
	8 51		83	W	0·5	Slight		To red at top : to violet at base.
November 1	8 53		12	E			1	0. 5 A both ways at several places and 1 A both ways at one place.
	8 30		28	W	1			
4	9 5		19	W	0·5			At the top of a jet.
5	8 52	Equator		E		Slight		
	8 56		21·5	E		1		
7	11 18	41		W	0·5			At top.
9	9 40		18·5	E	0·5			Do.
10	8 50		64	W		1		Do.
15	8 40	14		E		Slight		
	8 40	9		E		Do.		
	8 52		11	W		1		
16	8 37	35·5		W		Slight		
19	8 47	12		W	0·5			
22	8 43		53	W	Slight			

Date.	Hour I.S.T.		Latitude.		Limb.	Displacement.			Remarks.
			North.	South.		Red.	Violet.	Both ways.	
1917.	H.	M.	°	°		A	A	A	
November 22 —*continued.*	8	35	15		W	0·5			
	8	35	8		W	0·5			
	8	36	Equator		W	1			
	9	10	75		W		Slight		
23	8	30		58	E	Slight			
	8	27		80·5	W	0·5			No prominence.
30	8	43		18·5	E	Slight			
	8	56	17·5		W	1			
	8	57	21		W	0·5			
December 1	8	40		89		Slight			
	8	55	21		W	1			
2	8	28	23		W	2			At different places. 1 A to violet also at some positions.
3	8	54		28	W		Slight		
	8	55		5·5	W	Slight			
4	8	23	83		E	Do.			At top.
	9	16		48	E	Do.			
5	8	45	12		E		Slight		
	8	50		26	E		1·5		
	9	30		17·5	W	1	1		1 A to red at southern end and 1 A to violet over the rest of the prominence. Prominence 7° broad.
	8	22	39·5		W	1	Slight		
	9	16	62·5		W	Slight			
8	9	12	20		E		Slight		
	9	14	2		E		Do		
10	9	35		19	E	Slight			
12	10	55	12		E	Do.			At top.
	10	55	18		E		3·5		At base.
16	8	38		25	E	Slight			
18	8	45	1·5		W			1	
19	15	45		19	W	1·5			At base.
	15	49	4·5		W	1			
20	9	19	36·5		E		Slight		
	9	24		12	E		Do.		
	9	24		16	E			Slight	
21	8	51		8	E		Slight		
24	8	56	9		E	Slight			
25	8	46		13·5	W	Do.			At top.
	8	55	12·5		W	0·5			
	8	53	12·5		W			0·5	
26	8	43	31		W	Slight			
	8	53		21	W	Do.			
	8	55		53·5	W	Do.			
27	8	49		13	E	Do.			
	9	3		14·5	W	0·5			At top.
28	8	38		23	E		Slight		
29	8	55	37·5		E	Slight	Do.		To red at top, to violet at base.
	8	47		69	E	Do.			
	9	4	20		W			Slight	
	9	4	29		W	0·5			
30	8	40		28	E	Slight			
30	8	35	32		W	Do.			At top.
31	8	48		74·5	W			Slight	
31	9	4	18·5		W			0·5	

The total number observed was 172, of which 83 were in the northern hemisphere, 5 on the equator, and 84 in the southern hemisphere. Eighty-nine were on the eastern limb or 52 per cent of the whole. One hundred and four displacements were towards red, 69 towards violet, and 14 both ways simultaneously. One hundred and eighteen displacements were observed between the equator and latitude 30°, twenty-two from 31° to 60° and twenty-seven from 61° to the poles.

Reversals and displacements on the disc.

Two hundred and thirty-nine bright reversals of the Hα line, 18 dark reversals of D_3 and 61 displacements of Hα were recorded. These figures are approximately the same as for the previous half-year taking into

consideration the smaller number of effective days in the last half of the year compared with the first. The distribution east and west of the meridian of these phenomena was as follows :—

	East.	West.
Bright reversals of Hα	119	120
Dark reversals of D_3	11	7
Displacements of Hα	26	35

Of the displacements 38 were towards red, 15 towards violet and 8 both ways simultaneously.

Prominences projected on the disc as absorption markings.

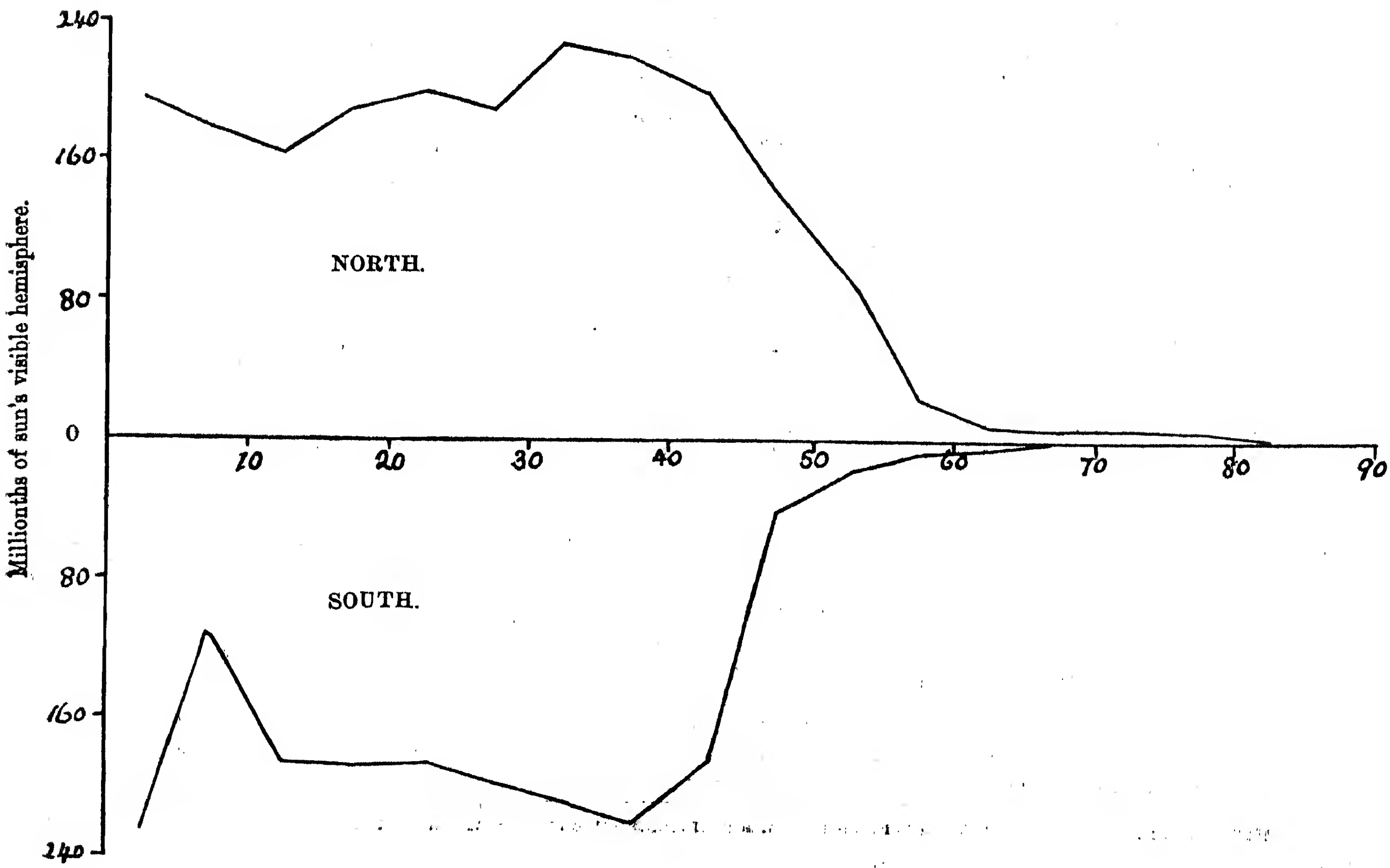
Photographs of the sun's disc in Hα light were obtained on 117 days counted as 107 effective days. The mean daily areas in millionths of the sun's visible hemisphere corrected for foreshortening, and the mean daily numbers are given below :—

	Areas.	Numbers.
North	2033	12·3
South	1771	11·8
Total ...	3804	24·1

Both areas and numbers show a large increase compared with the previous half-year although the prominences at the limb show a decrease of mean area. This indicates an increase of density of the prominences, excepting only those in the high latitude zones of activity above latitude 60° which have seldom given evidence of their presence on the disc.

The distribution of the prominence absorption markings in latitude is shown in the accompanying diagram.

Mean areas of Hα absorption markings.
July 1 to December 31, 1917



The regions of the greatest activity here indicated are the same as shown by the prominences at the limb (excepting the high latitude prominences), viz., at the equator and between latitude 30° to 35° north and 35° to 40° south.

The distribution east and west of the central meridian shows the usual excess at the east side the percentage east being 52·67 in the case of areas and 52·76 in the case of numbers. This is the same order of difference between east and west as was found for the first half of the year. If the figures for the entire year are added there results a total of 4725 absorption markings of which 52·81 per cent of areas and 53·08 per cent of numbers were east of the meridian. The most probable excess due to chance is 0·49 per cent on either side, while the chances of excesses of 2·81 per cent and 3·08 per cent on either side are respectively 1700 times and 7700 times less likely than equality on both sides.

KODAIKANAL OBSERVATORY,
2nd March 1918.

J. EVERSHED,
Director.

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Kodaikanal Observatory.

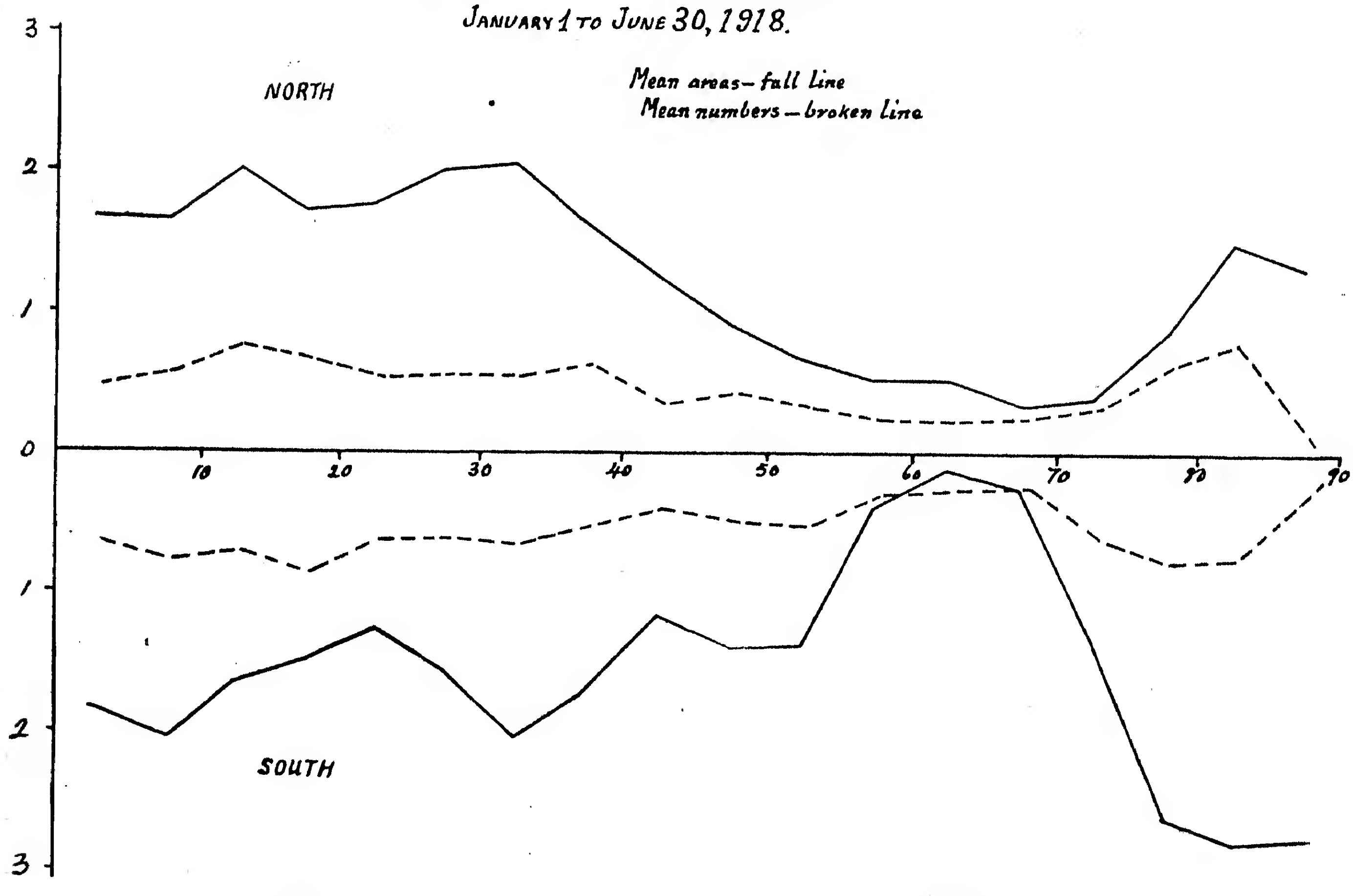
BULLETIN No. LIX.

SUMMARY OF PROMINENCE OBSERVATIONS FOR THE FIRST HALF OF THE YEAR 1918.

The distribution of prominences observed and photographed during the half-year ending June 30, 1918, is represented in the accompanying diagram. The full line gives the mean daily areas and the broken line the mean daily numbers for each zone of 5° of latitude. The ordinates represent tenths of a square minute of arc for the full line and numbers for the broken line. The means are corrected for incomplete or imperfect observations, the total of 171 days being reduced to 151 effective days.

MEAN AREAS AND MEAN NUMBERS OF PROMINENCES.

JANUARY 1 TO JUNE 30, 1918.



The most striking change since the previous half-year is the great increase in the south polar prominences; there is also a further increase of latitude of the polar prominences, which are now shown to envelop

both poles. The regions of minimum activity between the polar and mid-latitude prominences are shown between 65° and 75° in the north and between 60° and 65° in the south. In this last zone the activity fell to a very low ebb. At the equator prominence activity shows a marked decrease compared with the previous half-year.

The mean daily areas and daily numbers corrected for imperfect records are given below :—

	Mean daily areas (square minutes).	Mean daily numbers.
North	2·28	8·77
South	2·72	9·39
Total ...	5·00	18·16

This indicates a very slight increase over the previous half-year in areas and a decrease of 9 per cent in numbers, but both areas and numbers are less than during the first six months in 1917. Owing to the great increase in activity of the south polar prominences and of the zone between 45° and 55° south, the southern hemisphere now shows a preponderance over the northern. During the years 1916 and 1917 the northern hemisphere has exceeded the southern in prominence activity.

The monthly, quarterly and half-yearly frequencies and the mean height and extent of prominences are given in the following table. The frequencies are derived from the number of effective days :—

TABLE I.—ABSTRACT FOR THE FIRST HALF OF 1918.

Month	Number of days of observation.		Number of prominences.	Mean daily frequency.	Mean height.	Mean extent.
	Total.	Effective.				
1918.					″	°
January	27	25	522	20·9	41·3	4·31
February	28	26	540	20·8	31·5	3·60
March	31	30	506	16·9	34·1	4·50
April	30	27	504	18·7	32·4	3·83
May	27	19	288	15·2	35·1	3·53
June	28	24	414	17·3	31·5	3·51
First quarter	86	81	1568	19·4	35·6	4·13
Second quarter	85	70	1206	17·2	32·7	3·65
First half-year	171	151	2774	18·4	34·3	3·92

The mean height of a prominence and the mean number of prominences have diminished. The mean extent has very slightly increased.

Distribution east and west of the sun's axis.

An excess of both areas and numbers had been noticed on the west limb in the second half of 1917. It continued and was greater in amount in the first half of 1918. The figures are given in the following table :—

1918 January to June.	East.	West.	Percentage east.
Number observed	1323	1437	47·93
Total areas in square minutes	358·0	397·8	47·36

There is no marked difference in the mean brightness of an eastern or western prominence.

Metallic prominences.

The following metallic prominences were recorded in the half-year :—

TABLE II.—LIST OF METALLIC PROMINENCES OBSERVED AT KODAIKANAL, JANUARY TO JUNE 1918.

Date.		Hour I.S.T.		Base.	Latitude.		Limb.	Height.	Lines.
					North.	South.			
1918.		H.	M.	°	°	°		"	
January	1	8	25	1	19·5		W	35	4924·1, 5016, 5018·6, b_1, b_2, b_3, b_4, 5197·7, 5234·8, 5276·2, 5284·2, 5316·8, 5383·6, 5535·06, D_1, D_2, 6677.
	3	8	42	2	5		W	15	b_1, b_2, b_3, b_4, 5316·8, 5363·0, D_1, D_2, 6677.
	8	8	45			11	W	110	4924·1, 5018·6, 5197·7, 5234·8, 5276·2, 5284·2, 5316·8, 5535·06, D_1, D_2, b_1, b_2, b_3, b_4. 6677 and 7065 slightly bright.
	14	9	2			17	E	40	D_1, D_2, b_1, b_2, b_3, b_4, 5316·8, 4924·1.
	28	9	18			32	E	15	D_1, D_2, b_1, b_2, b_3, b_4, 5316·8, 6677.
	28	8	58	2	18		W	50	4924·1, 5018·6, 5234·8, 5276·2, 5316·8, D_1, D_2, 6677. All very bright.
	31	9	35	3	27·5		W	30	4924·1, 5016, 5018·6, b_1, b_2, 5197·7, 5208·7, 5234·8, 5276·2, 5314·8, 5363·0, 5535·06, D_1, D_2, 6677, 7065. All very bright.
February	1	8	36		12		E	15	D_1, D_2, b_1, b_2, b_3, b_4.
	10	8	27			13·5	E	35	b_1, b_2, b_3, b_4, 5316·8, D_1, D_2, 6677, 7065.
	11	8	42	4	2		E	20	4924·1, 5018·6, b_1, b_2, b_3, b_4, 5197·7, 5234·8, 5276·2, 5284·2, 5316·8, 5363·0, 5397·3, 5535·06, D_1, D_2, 6677, 7065.
	21	8	48	10	12		E	35	4924·1, 5016, 5018·6, b_1, b_2, b_3, b_4, 5197·7, 5234·8, 5276·2, 5284·2, 5316·8, 5363·0, 5535·06, D_1, D_2, 6677, 7065.
	26	8	44			21	W	30	D_1, D_2, b_1, b_2.
	26	8	37	2	39·5		W	10	D_1, D_2, b_1, b_2, b_3.
March	9	9	00	2	25		E	25	D_1, D_2, b_1, b_2, b_3, b_4.
	19	8	37		21		W	50	D_1, D_2, b_1, b_2.
	21	8	27	10	20		W	65	6677, D^1, D_2, 5316·8, b_1, b_2, b_3, b_4, 5016.
	30	8	30	7	14·5		E	70	D_1, D_2, b_1, b_2, b_3, b_4, 5316·8.
	31	8	32	6		16	E	125	D_1, D_2, b_1, b_2, b_3, b_4, 5316·8.
April	4	8	42	4	20		E	60	4924·1, 5016, 5018·6, b_1, b_2, b_3, b_4, 5234·8, 5276·2, 5316·8, D_1, D_2, 6677, 7065.
	7	8	38			21	W	15	D_1, D_2, b_1, b_2, b_3, b_4, 6677, 7065, 4924·1, 5016, 5316·8
	8	8	37	4	3		E	10	5016, b_1, b_2, b_3, b_4, 5234·8, 5276·2, 5316·8, 5363·0, D_1, D_2, 6677, 7065.
	9	8	29			18	E	45	D_1, D_2, b_1, b_2, b_3, b_4.
	10	8	42	1	22		E	20	4924·1, 5016, 5018·6, b_1, b_2, b_3, b_4, 5316·8, D_1, D_2, 6677, 7065.
	17	8	33			19	W	10	4924·1, 5016, 5018·6, b_1, b_2, b_3, b_4, 5197·7, 5316·8, D_1, D_2, 6677.
	21	8	16	1		24	E	20	D_1, D_2, b_1, b_2, b_3, b_4, 5316·8, 6677, 7065.
	22	8	28	2		19	W	10	4924·1, 5016, 5018·6, b_1, b_2, b_3, b_4, 5316·8, D_1, D_2, 6677, 7065.
	24	8	46	5		13·5	E	40	D_1, D_2, b_1, b_2, b_3, b_4.
May	2	8	48	16	15		E	80	4922·4, 4924·1, 5016, 5018·6, b_1, b_2, b_3, b_4, 5197·7, 5234·8, 5276·3, 5284·2, 5316·8, 5321·2, 5363·0, 5535·06, D_1, D_2, 6677, 7065.
	5	8	26	1		18	E	25	6677. Whole prominence seen in it.
	5	8	34	2		24	W	15	D_1, D_2, b_1, b_2, b_3, b_4, 5316·8, 6677.
	6	9	25			17	E	—	D_1, D_2, b_1, b_2, b_3, b_4.
	11	8	36			25·5	E	—	D_1, D_2, b_1, b_2, b_3, b_4, 6677.
	30	9	8	1	18·5		E	15	D_1, D_2, b_1, b_2, b_3, b_4, 5316·8, 4924·1, 5016, 6677.
June	10	8	45	5	23·5		W	20	4924·1, 5018·6, b_1, b_2, b_3, b_4, 5316·8.
	11	10	15		26		W	25	D_1, D_2. Slightly bright.

The metallic prominences recorded above were distributed as follows :—

—	Number.	Mean latitude.	Extreme latitudes.
		°	° °
North	19	18·1	2, 39·5
South	16	19·3	11, 32

Twenty were recorded in the eastern hemisphere and fifteen in the western.

Displacements of the hydrogen lines.

Particulars of the displacements observed in the prominences or chromosphere are given in Table III.

TABLE III.—DISPLACEMENTS OF THE HYDROGEN LINES.

Date.		Hour I.S.T.		Latitude.		Limb.	Displacement.			Remarks.
				North.	South.		Red.	Violet.	Both ways.	
1918.		H.	M.	°	°		A.	A.	A.	
January	1	8	36		10	W			Slight	
	1	8	25	19·5		W	Slight			
	3	8	26		21·5	E	0·5			
	3	8	25		30	E	Slight			
	3	8	42	5		W		Slight		
	4	9	17	11·5		E		0·5		
	4	9	2	47		W	0·5			
	5	8	47	15		E	2			
	5	8	35		60	E	Slight			
	5	8	30		75	W	Do.			
	6	8	39	80		E		Slight		At base.
	6	9	3	57		E	1	0·5		To red at top ; to violet at base.
	6	8	56		47·5	W		Slight		At base.
	6	8	53		10·5	W		0·5		Do.
	6	8	52	10		W	Slight			At top.
	7	8	50		40·5	E	Do.			
	7	9	0	35		W		0·5		
	8	8	44		8·5	W	0·5			
	9	8	55		8	E		Slight		
	10	8	50	60		E		Do.		
	10	9	1		13·5	E	Slight	Do.		To red at top ; to violet at base.
	10	9	7		61·5	E	0·5			
	12	8	25	79		E		Slight		
	12	8	37	61		E	Slight			Over upper part.
	12	8	42	18		E	0·5	0·5		At different points.
	12	8	32	26		W	Slight			
	14	8	37		41	E	2	3		To red at base ; to violet at top.
	14	8	3		85·5	W			Slight	
	17	8	58	24·5		W	Slight	Slight		
	20	8	55	40		E	Do.			
	20	9	0		8	E		Slight		
	20	9	3		16	E	1			
	20	8	45	70·5		W	0·5			
	22	9	2	10		E	0·5			
	22	9	23		57·5	W	Slight			
	22	8	52	19		W	1			
	22	8	50	52		W	Slight			
	22	8	50	61		W		Slight		At base.
	22	8	40	89		W		Do.		Do.
	28	9	18		32	E			Slight	
	28	9	5		28·5	W	2			At top.
	28	8	58	18		W		0·5		
	28	8	52	45		W		Slight		At northern end.
	30	8	25	78·5		E	0·5			
	30	8	25	75		E	Slight			
	30	8	24	70		E		Slight		

Date.		Hour I.S.T.		Latitude.		Limb.	Displacement.			Remarks.
				North.	South.		Red.	Violet.	Both ways.	
1918.		H.	M.	°			A.	A.	A.	
January—*cont.*	30	8	41		16	W			1	
	30	8	33	57·5		W			0·5	
	31	9	20	54		E		1		
	31	9	35	27·5		W	1·5	0·5		
February	1	8	45	18·5		E			1	Symmetrically.
	1	8	50		25	W		3·5		
	2	8	40	37		E		0·5		
	2	8	50		32	E	Slight			
	2	8	52		46·5	E			0·5	
	2	8	55		56·5	E	Slight			
	2	8	37	7		W	0·5			
	2	8	28	59·5		W	0·5			
	2	8	27	66·5		W	Slight			
	2	8	24	84		W		Slight		
	3	9	15		20	W		1·5		
	3	9	18		10	W		2		
	4	8	35		11	W	0·5			
	4	8	34	11		W		Slight		
	5	8	47	17		E		0·5		
	8	8	50		19	E		1		
	9	8	43		49	E		Slight		
	9	8	50		71	W	0·5			
	10	8	30	15		E	Slight	Slight		
	10	8	27		13·5	E			Slight	To red at top ; to violet at base.
	10	8	17		73	W	0·5			
	10	8	18		78·5	W	Slight			
	11	8	30	62		E		Slight		
	11	8	42	11		E			Slight	At northern end.
	11	8	40		19	W		Slight		
	12	8	22	83		E		Do.		
	12	8	15	68		E		Do.		
	12	9	10		25	E		Do.		At base.
	12	9	5		47·5	W			Slight	At top.
	12	9	0		31	W	Slight			
	12	8	50	26		W		Slight		
	12	8	50	22·5		W	0·5			
	13	8	45	33·5		E	3	2		
	13	8	43	6·5		E	Slight	Slight		To red at top ; to violet at base.
	18	8	43		3 5	E		0·5		Do.
	18	8	42		51·5	W	1·5			
	19	8	46	2		W	Slight			
	19	8	39	80		W	0·5			
	19	8	38	86		W	Slight			
	21	8	48	12		E	4	2		
	21	8	27		19·5	W		Slight		
	22	11	30	20		E	1			
	22	14	20	19		W	1·5			
	23	9	11		59·5	E	Slight			
	24	8	3	7		W	Do.			
	25	8	32		52·5	W		1		
	25	8	39	71·5		W	0·5			
	25	9	3		55	E	0·5			
	25	8	44		22	W	0·5			
	25	8	25	34		W		Slight		
	25	8	32	55·5		W		1		
	28	8	39	62·5		E		0·5		
	28	8	52	28		W		Slight		
	28	8	27	55·5		W	1			
March	2	8	32	51·5		E		2		At top.
	2	8	55	51·5		E	0·5			At base.
	2	8	44	13·5		W		Slight		At top.
	3	8	46		76	E	1	1·5		
	3	8	43		74·5	W			Slight	To red at top ; to violet at base.
	3	8	30		22	W		1		At top.
	3	8	28		17·5	W	0·5			Do.

Date.	Hour I.S.T.		Latitude.		Limb.	Displacement.			Remarks.
			North.	South.		Red.	Violet.	Both ways.	
1918.	H.	M.	°	°		A	A	A	
March—*cont.* 4	8	49	83		...		Slight		
4	8	36		20	E	Slight			
5	9	23	57·5		E			1	
5	8	57		41·5	E		0·5		
5	9	4		72	W		Slight		
5	8	40	9		W		Do.		
5	8	30	71·5		W	Slight			
7	8	29	69		E		Slight		
7	9	24	60		E	Slight			
7	8	59	17		E	1	0·5		
7	9	10		7	E	Slight			At base.
7	9	10		4·5	E			Slight	Over the whole base (13°).
7	9	15		13·5	E	Slight			
7	8	55		39·5	W		0·5		At base over 4°
7	8	50		19	W	Slight			Over almost the whole prominence (30″ high).
7	8	45	10		W		Slight		
7	8	42	26		W	Slight	1		To red at base ; to violet at top.
7	8	39	50·5		W	1	1		
8	9	6	16		E		1·5		
9	8	38	46		E		Slight		At base.
9	9	00	25		E	0·5	0·5		To red at base ; to violet at top.
9	8	54		7	W	1·5	Slight		
9	8	46	75·5		W		Do.		
10	8	36	25 to 33		E		1		
10	9	00	Equator		E	1			
10	9	10		73	E	1			
10	8	20		11	W		1		
10	8	20		10 and 8	W	0·5			
10	8	20		4	W			1	
10	8	49	37·5		W		0·5		At base.
12	8	38	82·5		E	Slight.			
12	8	42	80		E	0·5			
12	8	57	36		E		Slight		
12	8	58	29		E		Do.		
12	9	6		57·5	W	Slight			
12	9	7		53·5	W	2			
12	8	54		22	W	0·5			
14	9	2	11		E	0·5			
14	9	2	8		E		Slight		
14	9	19		38	W		0·5		
14	9	9		21	W	0·5			
14	8	59	45·5		W	1			
16	8	14	81·5		E		Slight		
16	8	40	72·5		E	0·5			
17	8	30	74·5		E		Slight		At base.
17	9	2		82·5	E	0·5			
17	8	38	12·5		W			0·5	
17	8	35	49·5		W			0·5	
17	8	33	69		W		0·5		At base.
18	8	39	30		W		Slight		At top.
19	8	37	9		E	1			
19	8	37	24		E	Slight			
19	8	59		15	E	Do.	Slight	2	
19	9	4		82	E	0·5			
19	9	6		65·5	W		0·5		
19	8	40	8		W		Slight		
19	8	41	4		W	0·5			
19	8	37	27		W	2	0·5		
19	8	35	45		W	Slight			
20	8	31	18		W		0·5		
21	8	23		50·5	W		Slight		
21	8	25	7·5		W	0·5	1		
21	8	27	20		W	1			At top.
21	8	29	31		W	1			Do.
21	9	6		9·5	E	Slight			

Date.		Hour I.S.T.		Latitude		Limb.	Displacement.			Remarks.
				North.	South.		Red.	Violet.	Both ways.	
1918.		H.	M.	°	°		A	A	A	
March	23	8	52		29·5	W		0·5		
	25	8	32		47·5	W	1			
	26	9	59	82		E	Slight			
	26	10	9	23		W		2		
	30	8	30	14·5		E	2			
	31	8	27		17	W		Slight		
April	1	8	27		21	E	0·5			
	1	8	36		19	W		Slight		
	1	8	35	34·5		W	0·5			
	4	8	42	18		E	1	0·5		
	6	8	45		8	W		Slight		
	8	8	37	3		E	Slight			At top.
	8	8	42		11	E	2			Do.
	8	8	47		80·5	E	0·5			At base.
	9	8	30	17		W		1·5		
	9	8	37	1		W		3		At top.
	10	8	40	66·5		E		Slight		
	10	8	42	22		E	0·5			
	11	8	54	40·5		E	Slight			
	11	8	55	37		E		0·5		At top.
	11	8	59		26	E			0·5	
	12	8	17	18·5		W	Slight			
	13	8	37	84·5		—		Slight		
	13	8	44	7		W		0·5		
	13	8	43	20		W			Slight	
	14	8	25		53	W		0·5		
	14	8	20	20		W		0·5		At top.
	15	9	00	58		E		0·5		
	15	8	43		84	W	1			
	15	8	40		42·5	W		0·5		
	15	8	38		17·5	W		0·5		At base.
	16	8	25	57·5		E		0·5		
	16	8	20		66·5	W		1		
	17	8	46	8		W	1·5			At top.
	18	9	24	Equator		E		0·5		
	18	8	58		1	W	0·5			
	18	8	55	29 to 33		W	0·5			At top.
	18	8	55	26		W		2		At base.
	19	7	58	69		E		0·5		
	19	8	3		1·5	W		Slight		At base.
	20	8	56	49·5		E		0·5		
	20	8	50		42	E		Slight		At top.
	20	8	36	10		W	2	1		
	20	8	33	32		W			1	
	21	8	18	26		E	Slight			
	21	8	16		23	E	0·5			At top.
	21	8	25	49·5		W		Slight		
	22	8	20	25		E	3			
	22	8	21	18		E	2			
	22	8	33	10		E	1			
	22	8	34	2		E	3			
	22	8	28		19	W	1	2		
	23	8	38		10	E	0·5			
	23	8	46	71·5		W		Slight		
	24	8	27	29		E		0·5		
	24	8	33	30		W	1·5			At top.
	25	8	45	20·5		E	Slight			
	25	8	49	Equator		E		Slight		
	25	8	51		20	E		0·5		At top.
	25	8	33	84		W	Slight			
	26	8	47	10		W	2			
	28	8	30		46·5	E		Slight		At top.
	28	8	46	9·5		E	Slight			Do.
	28	8	53	13·5		W		Slight		

Date.	Hour I.S.T.	Latitude.		Limb.	Displacement.			Remarks.
		North.	South.		Red.	Violet.	Both ways.	
1918.	H. M.	°	°		A	A	A	
May 2	8 28	40		E	0·5			
2	8 48	15		E	2	Slight		To red at base, to violet at top.
2	8 40		85	E		0·5		
4	12 14	13		E		Slight		
4	8 26		18	E			0·5	
4	8 20		39	E	Slight			
6	9 20	23·5		E	Do.			
6	9 21	3		E	Do.			
6	9 10		14	W		Slight		
14	9 6	16		E	0·5			
14	9 8	5·5		E			Slight	
14	8 57	19		W		1		
14	8 55	42		W	Slight			
15	9 3		16	E	Do.			
15	9 16	11		W	1·5			
28	8 0	71		E	0·5			
30	9 3	10		E		Slight		
31	9 30		13·5	W		1·5		
June 1	8 42	46		W			0·5	
4	9 11		32	E	0·5	0·5		In different places.
4	9 10		35	E		1		
4	9 15		86	E			0·5	
6	8 43		61	W		1		
7	8 55	61		E		1·5		
8	8 26	65		E	2			At top.
8	8 38		11	W	Slight			Do.
9	8 39		35	E	1			
10	8 45	23·5		W	2			At top.
10	8 40	65		W		0·5		
11	10 15	26		W		1		
12	9 5	5		W			0·5	
16	8 22		68	E	0·5	1		To red at base, to violet at top.
17	8 52	9		E		1		At top.
17	8 56	Equator		E	3			At base.
17	8 47		51	W		1		
18	8 34		7	E	Slight			
18	8 43		74	W	0·5			
18	8 15	71		W	Slight			
19	8 38		65	E	Do.			
27	8 45		11·5	W	0·5			
28	9 0		2·5	W	1			

The total number of displacements was large, namely 281. Four of these were on the equator, the rest were distributed as follows :—

Latitude.	North.	South.
1° to 30°	86	59
31 to 60	39	32
61 to 90	39	22
Total ...	164	113
East limb	136	
West limb	143	
At pole	2	

There were 146 displacements towards red and 135 towards violet ; these include 25 in which the shifts were in both directions in the same prominence. The preponderance towards red is less than the average of recent years.

Reversals and displacements of the C line on the disc.

252 bright reversals of the Hα line, 35 darkenings of the D_3 line, and 97 displacements of the Hα line were recorded. They were distributed as follows :—

	North.	South.	East.	West.	Percentage east.
Bright reversals of Hα	125	127	126	126	50·0
Dark reversals of D_3	19	16	17	18	48·6
Displacements of Hα	58	39	42	55	43·3

Of the displacements 57 were towards the red, 27 towards the violet and 13 both ways simultaneously.

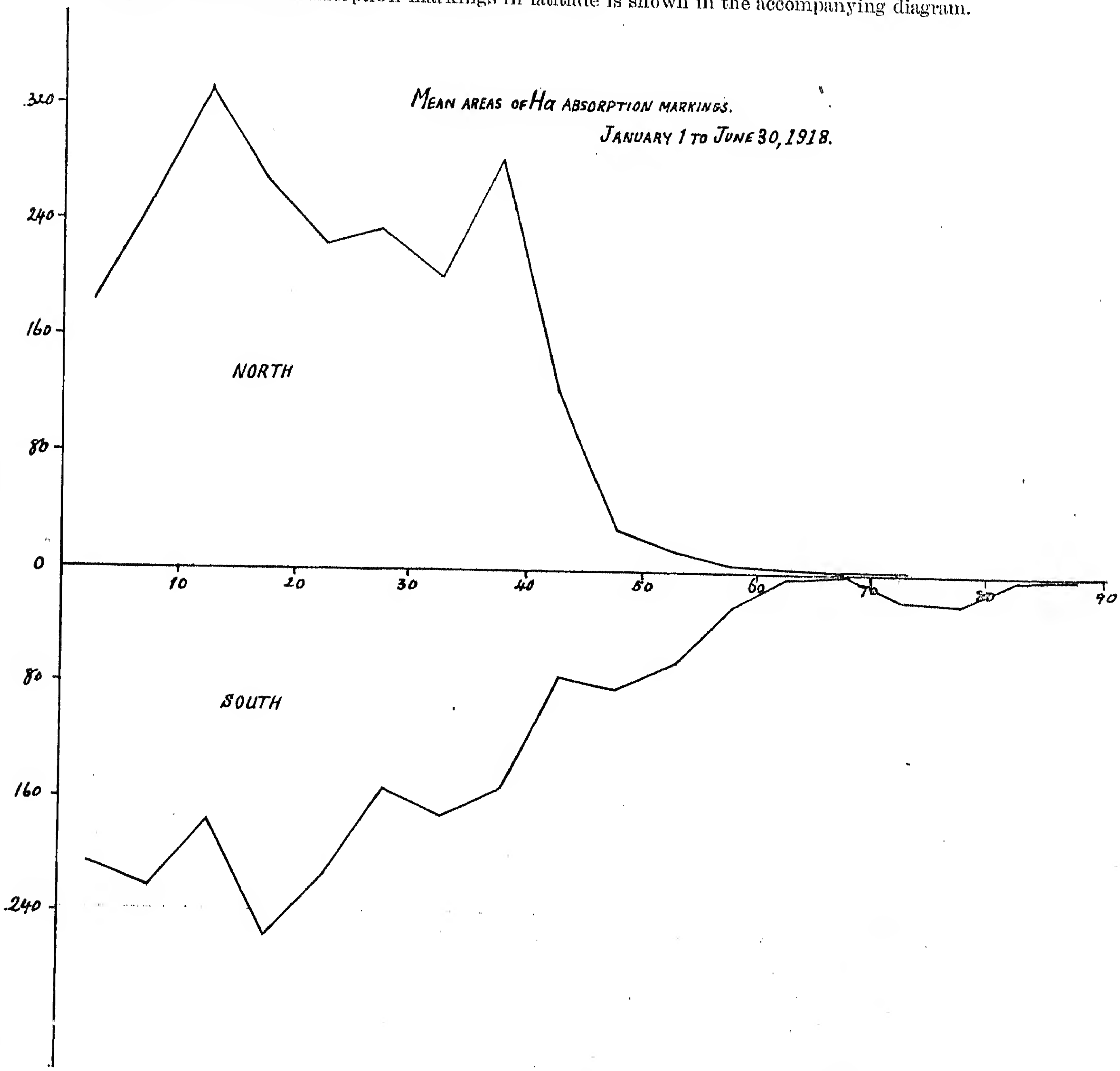
Prominences projected on the disc as absorption markings.

Photographs of the sun's disc in Hα light were obtained on 144 days counted as 135 effective days. The mean daily areas in millionths of the sun's visible hemisphere corrected for foreshortening, and the mean daily numbers are given below :—

	Areas.	Numbers.
North	2149	13·9
South	1837	12·5
Total ...	3986	26·4

Both areas and numbers have continued to increase.

The distribution of the absorption markings in latitude is shown in the accompanying diagram.



The curves are much less flat than in the previous half-year, well marked maxima having developed in the regions + 10° to + 15°, +35° to + 40°, and −15° to −20°. Regarding these markings as representing the denser prominences, it is seen that only the equatorial and mid-latitude prominences are in general dense enough to appear on the disc as absorption markings, whilst the polar prominences although so conspicuous in the number and area curves for this period must be of very low density since they have not been recorded as dark markings in the northern polar region, and are only feebly represented in the south.

Unlike prominences at the limb these markings still show an excess on east of the meridian, the percentage east being 52·03 in the case of areas and 51·66 in the case of numbers. The most probable excess due to chance is 0·56 per cent on either side. There has been a steady fall in the eastern excess since the second half of 1916 when the percentage east of areas was 55·8. In the case of prominences at the limb there has been during thiss ame interval of two years a gradual change from an eastern to a western excess.

KODAIKANAL OBSERVATORY,
28th August 1918.

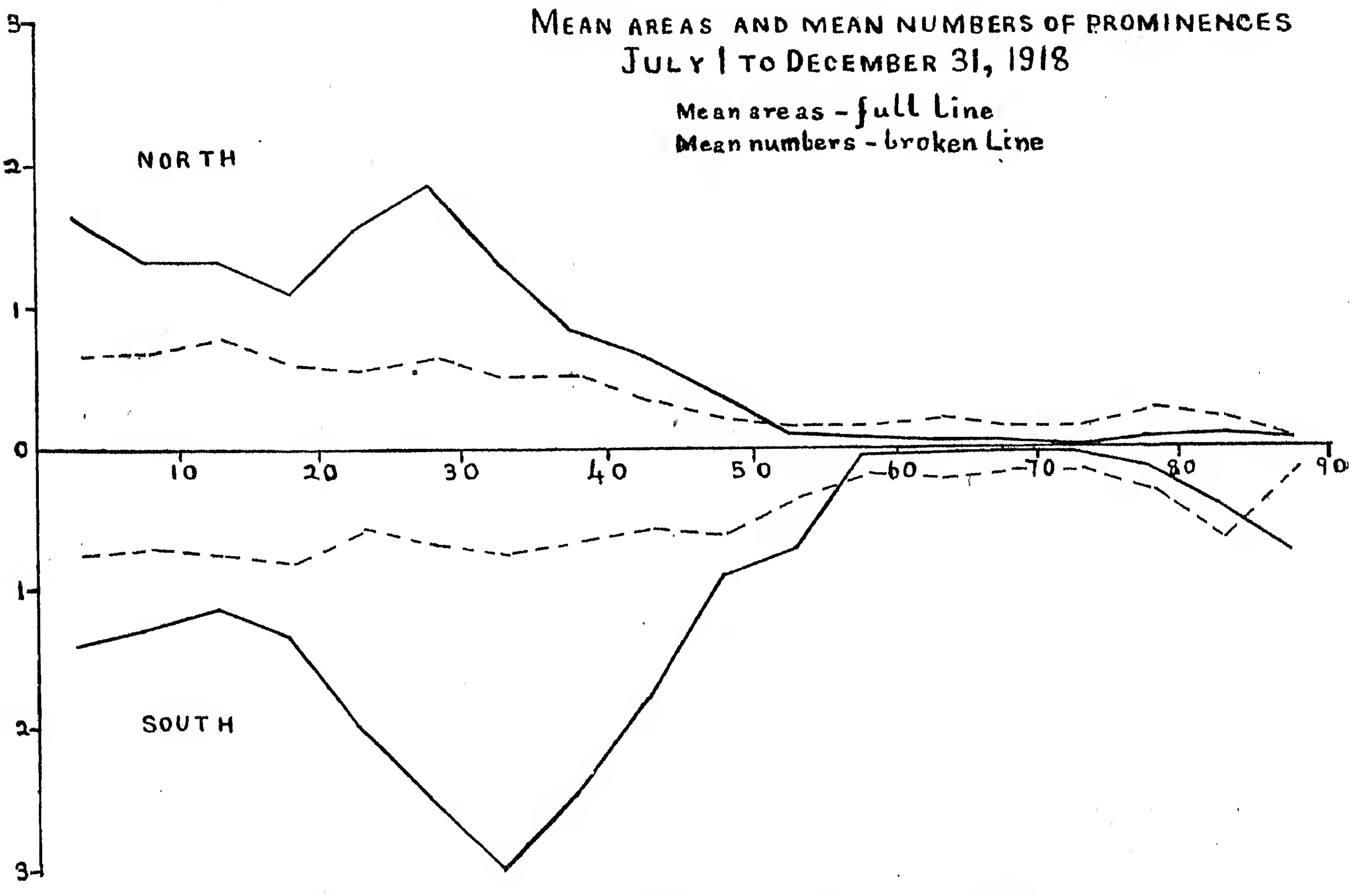
J. EVERSHED,
Director, Kodaikanal and Madras Observatories.

Kodaikanal Observatory.

BULLETIN No. LX.

SUMMARY OF PROMINENCE OBSERVATION FOR THE SECOND HALF OF THE YEAR 1918.

The distribution of prominences observed and photographed during the half-year ending December 31st, 1918, is represented in the accompanying diagram. The full line gives the mean daily areas and the broken line the mean daily numbers for each zone of 5° of latitude. The ordinates represent tenths of a square minute of arc for the full line and numbers for the broken line. The means are corrected for incomplete or imperfect observations, the total of 151 days being reduced to 122 effective days.



The outstanding feature in the prominence distribution in latitude is the sudden fall in the activity of the polar regions. The northern high latitude region ceased to produce prominences of any size after July, but the southern polar regions displayed a feeble activity up to the end of the year. This phase of the prominence cycle is a fairly definite one and seems to occur when the high latitude zones of activity, progressively

advancing in latitude, finally reach and envelop the poles. The southern zone of prominences was a little behind the northern in advancing towards the pole, its final dissolution therefore occurred later. The disappearance of the polar prominences occurred previously in the years 1895 and 1907, indicating periods of 12 years and 11 years respectively.

The mean daily areas and daily numbers corrected for imperfect records are given below :—

	Mean daily areas (square minutes).	Mean daily numbers.
North	1·24	6·90
South	1·99	9·04
Total ...	3·23	15·94

The fall in activity here shown when compared with the corresponding figures for the previous half year is mainly the result of the dissolution of the polar prominences, but there is also a general reduction in all latitudes of the northern hemisphere. In the south the activity has increased between latitude 25° and 40°, and there results a marked preponderence of the south over the north.

Prominences generally attained a maximum development in the northern hemisphere early in 1917, whilst the southern maximum occurred during the first half of 1918. This delayed action of the south has caused a reversal of the relative activity of north and south which took place between the years 1917 and 1918. The mean brightness of the southern prominences in the second half of 1918 was slightly greater than that of the northern prominences.

The monthly, quarterly and half-yearly frequencies and the mean height and extent of the prominences are given in the following table. The frequencies are derived from the number of effective days :—

TABLE I.—ABSTRACT FOR THE SECOND HALF OF 1918.

Month.	Number of days of observation.		Number of prominences.	Mean daily frequencies.	Mean height.	Mean extent.
	Total.	Effective.				
1918.					″	°
July	29	23	396	17·2	32·2	3·42
August	26	19	276	14·5	35·4	3·84
September	29	24	352	14·7	34·2	3·22
October	29	25	389	15·6	33·9	3·31
November	15	12	228	19·0	27·3	2·27
December	23	19	321	16·9	28·0	2·39
Third quarter	84	66	1024	15·5	33·8	3·46
Fourth quarter	67	56	938	16·8	30·3	2·74
Second half-year	151	122	1962	16·1	32·1	3·12

The mean height and the mean extent of the prominences have diminished compared with the first six months of the year.

Distribution east and west of the sun's axis.

The distribution east and west of the sun's axis of both prominence numbers and areas is given in the following table :—

1918 July to December.	East.	West.	Percentage east.
Number observed	943	1015	48·06
Total areas in square minutes	211·0	184·2	53·38

The distribution has reverted to an eastern excess in the case of the areas.

Metallic prominences.

The following metallic prominences were recorded in the half year :—

TABLE II.—LIST OF METALLIC PROMINENCES OBSERVED AT KODAIKANAL, JULY TO DECEMBER 1918.

Date.		Hour I.S.T.		Base.	Latitude.		Limb.	Height.	Lines.
					North.	South.			
1918.		H.	M.	°	°	°		"	
July	10	8	50	5	7·5		W	20	4924·1, 5016, 5018·6, b_1, b_2, b_3, b_4, 5197·7, 5234·8, 5316·8, D_1, D_2, 6677.
	11	8	56	6	7		E	35	4924·1, 5016, 5018·6, b_1, b_2, b_3, b_4, 5197·7, 5231·6, 5276·2, 5284·2, 5316·8, 5362·0, 5535·0, D_1, D_2, 6677 and 7065.
	11	8	36	8	14		W	30	D_1, D_2, b_1, b_2, b_3, b_4, 5316·8.
	13	8	34	12		37	E	100	D_1, D_2, b_1, b_2, b_3, b_4, 5316·8.
	13	8	54	7	15·5		W	30	D_1, D_2, 5316·8, b_1, b_2, b_3, b_4, 4924·1, 6677 slightly bright.
	14	8	49		13		W	30	D_1, D_2, 5316·8, b_1, b_2, b_3, b_4, 5016, 6677 and 7065.
	18	9	23	5		17·5	W	60	D_1, D_2, b_1, b_2, b_3, b_4, 5316·8, 4924·1, 5016, 5018·6, 6677, 7065. All very bright.
	28	8	30	10	11		E	25	D_1, D_2, b_1, b_2, b_3, b_4, 5316·8, 6677, 7065, 5016, 5197·7.
August	8	9	22	23	4·5		W	120	D_1, D_2, b_1, b_2, b_3, b_4, 5316·8, 6677.
	24	8	46	1	13·5		W	75	4924·1, 5016, 5018·6, b_1, b_2, b_3, b_4, 5197·7, 5234·8, 5276·2, 5284·2, 5316·8, 5363·0, 5425·4, 5527·0, 5535·06 D_1, D_2, 6677, 7065.
September	7	8	45		Equator.		E	110	D_1, D_2, b_1, b_2, b_3, b_4 bright over the whole height of the prominence.
	21	8	30		15		W	60	4924·1, 5018·6, b_1, b_2, b_3, b_4, 5197·7, 5234·8, 5276·2, 5316·8, D_1, D_2, 6677 slightly bright.
October	10	9	5	9	27·5		W	55	D_1, D_2, b_1, b_2, b_3.
	23	8	56			14	W		D_1, D_2, b_1, b_2, b_3, b_4, 5316·8, 5018·6, 4924·1, 6677.
November	13	10	41	36		19	E	90	6677, D_1, D_2, b_1, b_2, b_3, b_4.
	26	12	18	9	10·5		W	65	6677, D_1, D_2, b_1, b_2, b_3, b_4, 5316·8, 5018·6, 4924·1, 5197·7, 5234·8, 5284·2, 5276·0.
December	8	8	50			10	W	20	D_1, D_2, b_1, b_2, b_3, b_4, 5316·8.
	13	9	36		12		E	30	D_1, D_2 slightly bright.
	13	9	22			20	W	20	D_1, D_2 b_1, b_2, b_3, b_4, 4924·1, 5316·8. Not seen at 9^h 45^m.
	20	8	40			8	W	15	D_1, D_2, b_1, b_2, b_3, b_4, 4924·1, 5316·8.
	24	8	44			26·5	E	20	D_1, D_2, b_1, b_2, b_3, b_4.
	26	9	45		12		W	15	D_1, D_2, b_1, b_2, b_3, b_4, 5316·8.
	28	8	55			31	W	50	D_1, D_2, b_1, b_2, b_3, b_4, 5316·8.
	28	8	45			10	W	20	4922·5, 4924·1, 5016, 5018·6, b_1, b_2, b_3, b_4, 5197·7, 5234·8, 5276·2, 5284·2, 5316·8, 5363·0, 5424·3, 5535·06, D_1, D_2, 6677, 7065.
	29	8	35	9		28·5	W	60	D_1, D_2, b_1, b_2, b_3, b_4, 5316·8. Whole prominence seen in b_1, b_2, b_3, b_4.
	30	9	45	5		6·5	W	60	4922·3, 4924·1, 5016, 5018·6, b_1, b_2, b_3, b_4, 5197·7, 5234·8, 5276·2, 5284·2, 5316·8, 5363·0, D_1, D_2, 6677, 7065. All lines very bright.
		8	35	17	24·5		W	75	4924·1, 5016, 5018·6, b_1, b_2, b_3, b_4, 5197·7, 5234·8, 5276·2, 5316·8, 5363·0, 5535·06, D_1, D_2, 6677, 7065. The lines bright over the whole base of the prominence and particularly at the southern end.
	31	8	37			24	W	30	4924·1, 5018·6, 5197·7, b_1, b_2, b_3, b_4, D_1, D_2, 5316·8.
		8	40	3		8·5	W	75	D_1, D_2, b_1, b_2, b_3, b_4, 5316·8.
		8	40		4		W		D_1, D_2, b_1, b_2, b_3, b_4, 5316·8.

The metallic prominences recorded above were distributed as follows :—

—	Number.	Mean latitude.	Extreme latitudes.
		°	° °
North	15	12·8	4, 27·5
South	14	18·6	6·5, 37
Equator	1	...	...

Only seven were recorded on the eastern limb against twenty-three on the western limb.

Displacements of the hydrogen lines.

Particulars of the displacements observed in the prominences or chromosphere are given in table III.

TABLE III.

Date.		Hour I.S.T.		Latitude.		Limb.	Displacement.			Remarks.
				North.	South.		Red.	Violet.	Both ways.	
1918.		H.	M.	°	°		A.	A.	A.	
July	2	11	40	13		W		Slight		
	4	8	50		68	E	Slight			
	7	8	50		62	E	1			
	7	8	30	15		W	2			
	7	8	26	67·5		W		Slight		
	8	8	38	77·5		W		1		No prominence.
	9	8	47	4		W			Slight	
	9	8	46	14		W			Do.	
	9	8	43	35		W		0·5		At base.
	9	8	25	79		W	Slight			
	10	8	36		40	E	Do.			
	10	8	50	7·5		W			Slight	
	11	8	33	73		E		1·5		No prominence.
	11	8	56	3		E	2			
	11	10	20	Equator		E	Slight	0·5		
	11	8	36	16		W	Do.			
	11	9	17	12		W	2	0·5		
	13	8	34		37	E		Slight		At base.
	13	8	54	15·5		W		Do.		At top.
	14	8	55	15		E		Do.		Do.
	15	8	48	10		E		2		Do.
	16	8	50	14·5		W			0·5	
	17	8	40	24		E	2·5			Whole prominence bodily shifted to red of the line.
	17	8	30		12	E		Slight		
	18	9	23		17·5	W	2	1		
	18	9	6	40		W		Slight		
	21	8	15		11·5	E	Slight			
	22	8	34		18·5	E	0·5			
	25	9	5	29		E	Slight			
	28	8	30	7		W	1·5			
	30	9	17	15		W		0·5		
August	4	9	1		41·5	W		Slight		
	6	8	59	2 to 6		W	0·5			At several places.
	6	8	59	10		W		0·5		
	6	8	54	12		W	Slight			
	6	8	53	16		W	1	2		
	6	8	52	20		W		1·5		
	6	8	52	25		W	1	1		
	6	8	50	41		W	0·5			
	7	8	48	20		E		1·5		
	8	9	11		23·5	E		2		At top.
	8	9	11		23·5	E		0·5		At base.
	8	9	22	4·5		W			Slight	
	12	8	38		16	W	1			
	16	10	8		29·5	E	1·5			At base.
	21	10	20		3·5	E	Slight			

Date.		Hour I.S.T.		Latitude.		Limb.	Displacement.			Remarks.
				North.	South.		Red.	Violet.	Both ways.	
1918.		H.	M.	°	°		A	A	A	
August	24	8	36	66		E			Slight	No prominence.
	26	8	30	3		W			2	
	26	8	40	7		W	Slight			At top.
	30	8	45		34·5	E	Do.			
September	2	8	40	7		W	Do.			
	3	8	36	19		W	0·5			
	4	9	45		16	E		Slight		
	7	8	49		23	E		Do.		
	7	8	31	34·5		W		Do.		
	8	8	45		7	E	Slight			
	10	8	48	6		W	Do.			
	19	9	22	53·5		W		Slight		
	21	8	33		19	W		Do.		At top.
	21	8	32		12	W	Slight			Do.
	23	8	37	71·5		E		Slight		
October	2	8	43		19·5	E	4	Do.		
	3	9	39	48		W			Slight	
	4	9	5	9		E		3		
	4	9	10		68	E	1			
	4	8	49	35·5		W		Slight		
	4	7	58	57		W	2		2	Not seen at 9h 14m.
	5	9	5	9		W		5		
	5	9	0	17		W				
	5	9	13	17		W	1			
	6	8	55	57·5		W		0·5		At top.
	7	8	54		32	W		2		
	7	8	56		16	W		0·5		
	10	9	5	24		W	5	1·5		
	11	10	25		42	E	4			
	11	10	25		40	E		Slight		
	20	8	28	45·5		W	0·5			
	21	9	10		20	W	0·5	3		
	23	9	5	27		E			Slight	
	23	8	56		14	W			1	
	24	8	36	61·5		E	Slight			
	25	8	33	23		W			1	To red.
									0·5	To violet.
	26	8	52	85		E	Slight			Not seen at 9h 15m.
	26	9	14	78		E	0·5			
	26	9	22	31		E			Slight	Over the streamer.
	26	9	9		34	W	Slight			
	27	8	44		27	E	1·5	0·5		
	27	8	29	1		W	1·5			
	27	8	29	6		W	Slight			
	27	8	26	27		W	Do.	Slight		To red at top ; to violet at base.
	28	9	4	6		E			Slight	
	28	8	54	16		W		0·5		
	28	8	54	12		W	1			
	28	8	54	9		W		2		
	28	8	54	6		W	1			
	28	8	50	31		W	0·5			
	29	8	56	8·5		W	1			
	29	8	56	16		W	1			
	30	8	43	62·5		E	Slight			
	30	8	44	62·5		E		1		
	30	8	40		77	W	1			
	30	8	33	1		W		Slight		
	31	12	0	20		W	1			
November	8	9	20		45	E			Slight	
	8	9	25		86·5	—		Slight		
	9	8	56	22		E		0·5		
	9	9	0		16	E			Slight	
	9	9	1		43·5	E		1		At top.
	9	8	47		27	W	0·5			
	9	8	40	67		W			Slight	
	10	8	45	15		E	2	Slight		

Date.		Hour I.S.T.		Latitude.		Limb.	Displacement.			Remarks.
				North.	South.		Red.	Violet.	Both ways.	
1918.		H.	M.	°	°		A	A	A	
November	10	8	58		11	E	3*		1·5	* At top.
	10	9	0		20	E	1	0·5		To red at base; to violet at top.
	10	9	4		61	E		0·5		
	10	8	39	11		W	Slight			
	13	8	15		4	E			6	Between 4° and 6°, the amount of displacement to violet varied from 1 A to 6 A at $10^h\ 30^m$. C was displaced 6 A both ways at several places $10^h\ 35^m$. Maximum amount 8 A to violet, very faint at $10^h\ 41^m$.
	14	10	6	12		W	Do.			
	16	8	58	11		E		Slight		At top.
	16	8	45	15		W			Slight	
	19	12	32	69		E	Slight			
	26	12	18	6		W	0·5			
	26	12	35	6		W		3·5		D_3 was also displaced 3·5 A.
	26	12	40	6		W		1		
	26	12	10	33·5		W	2	5		Violet displacement at top only.
	28	15	46		4	W		2		Over upper part of prominence (140″).
December	5	8	52	18		E		Slight		
	9	9	28		14	W		Do.		At base.
	10	9	3		18	W			Slight	
	10	9	2		12	W		Slight		
	13	8	41		71	W		Do.		
	13	9	22		20	W	Slight	1·5		To violet at base; to red at top.
	19	10	22		11	E			Slight	
	19	9	36		11	W	Slight			
	20	9	00	86·5		E	Do.			At base.
	20	8	45	5		W		Slight		
	21	9	39	72		E	Slight			
	21	9	48		25	E	2			
	21	9	34		44	W			0·5	
	21	9	33		32·5	W		Slight		
	21	9	31		2	W	1			
	22	8	56	76		E	0·5			
	22	9	15	3		E	1·5			
	22	10	22		22	E	0·5			
	22	8	59	51		W	1			
	22	8	57	81		W	Slight			
	23	9	40	73		E	0·5			
	23	9	31		8	E	1			Ghosts at about 9 A from C on both sides at northern end of prominence where it was fairly bright. Lat. + 14° E.
	23	9	45	38·5		W	1·5			
	24	8	52	51		E	2			No prominence.
	24	8	47	Equator		E	Slight	0·5		To red at base; to violet at top.
	25	8	52	10		E	Do.			
	26	9	38	87		E	Do.			
	26	9	55		68	W		1·5		No prominence.
	26	9	46	7		W		Slight		
	26	9	45	12		W		0·5		
	26	9	42	79·5		W		0·5		No prominence.
	28	8	50		9	W	2			At top.
	29	8	22		45	E		2		Prominence extended at top to −31° E. The amount of the displacement varied from 0·5 at − 45° E to 2 A at − 31° E.
	29	8	35		33	W		Slight		At top.
	29	8	39	26		W		Do.		
	30	8	25	83·5		E		1·5		
	30	9	42		6·5	W	6			At tops of streaks. Not seen at $9^h\ 45^m$.
	30	8	35	16		W			Slight	
	31	8	37		24	W	0·5			At top.
	31	8	40	4		W			0·5	

The total number of displacements was 165, of these 2 were on the equator, and the rest were distributed as follows :—

Latitude.	North.	South.
1° to 30°	66	38
31° to 60°	16	14
61° to 90°	21	8
Total ...	103	60
East limb	66	
West limb	98	
Pole	1	

There were 84 displacements towards red, 72 towards violet and 25 both ways simultaneously.

Reversals and displacements on the disc.

170 bright reversals of the Hα line, 9 dark reversals of the D_3 line and 50 displacements of the Hα line were recorded. They were distributed as follows :—

	North.	South.	East.	West.
Bright reversals of Hα	92	78	88	82
Dark reversals of D_3	5	4	6	3
Displacements of Hα	26	24	23	27

These figures and the number of displacements at the limb indicate a general reduction of solar activity amounting to about 40 per cent compared with the first 6 months of the year.

Of the 50 displacements of the Hα line 29 were towards red, 10 towards violet and 11 both ways simultaneously.

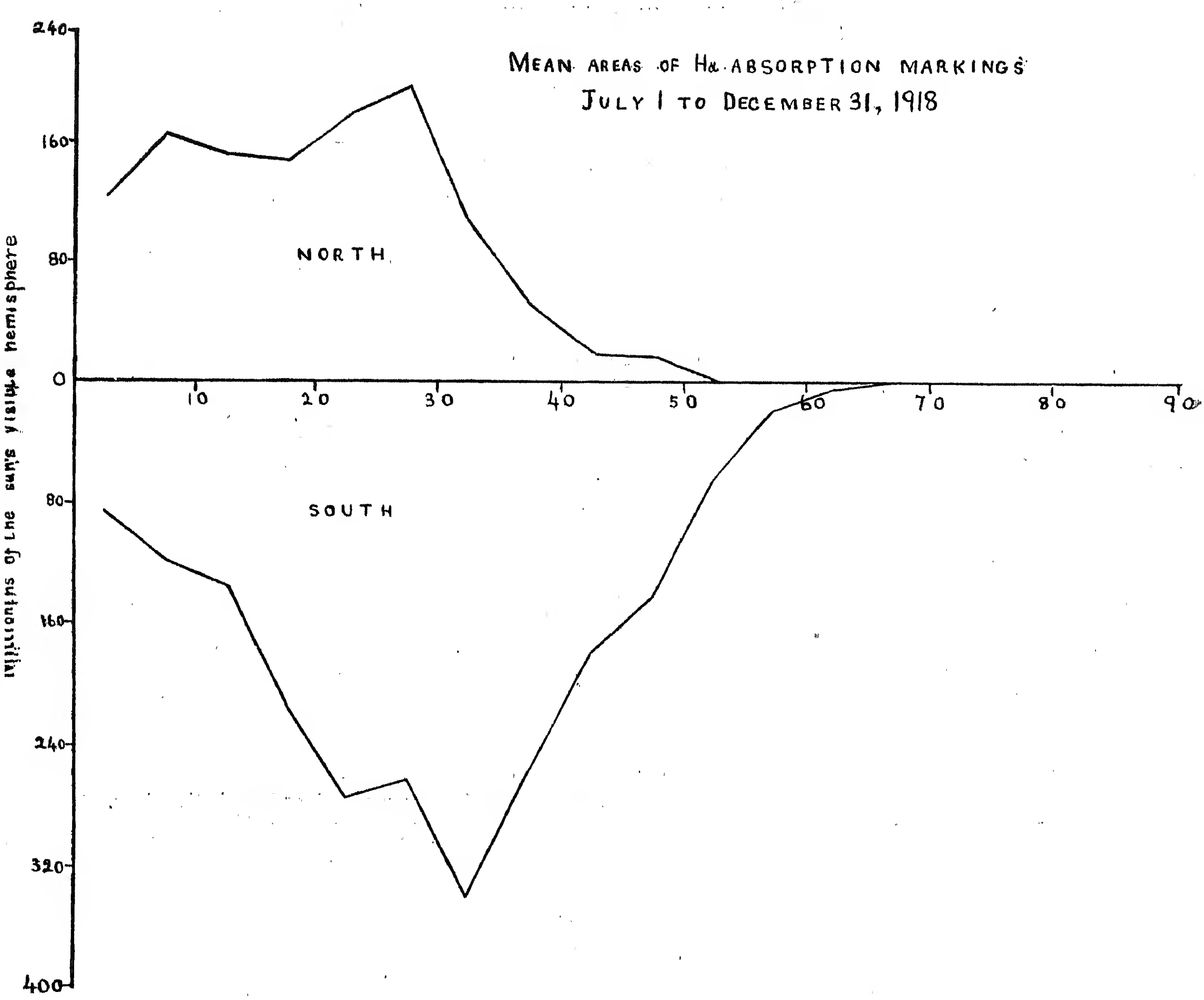
Prominences projected on the disc as absorption markings.

Photographs of the sun's disc in Hα light were obtained on 115 days counted as 98 effective days. The mean daily areas in millionths of the sun's visible hemisphere corrected for foreshortening, and the mean daily numbers are given below :—

	Areas.	Numbers.
North	1158	8·7
South	2075	13·2
Total ...	3233	21·9

The numbers and areas show an increase in the southern hemisphere but they have diminished on the whole since the previous half year about 19 per cent.

The distribution of the absorption markings in latitude is shown in the accompanying diagram.



The curve is very similar to that of the prominences at the limb showing a maximum activity in the zones 25°—30° north and 30°—35° south.

Both areas and numbers show an excess on the eastern hemisphere, the percentage east being for areas 52·94, and for numbers 53·90. The most probable excess due to chance is 0·73 per cent on either side.

KODAIKANAL OBSERVATORY,
17*th March* 1919.

J. EVERSHED,
Director, Kodaikanal and Madras Observatories.

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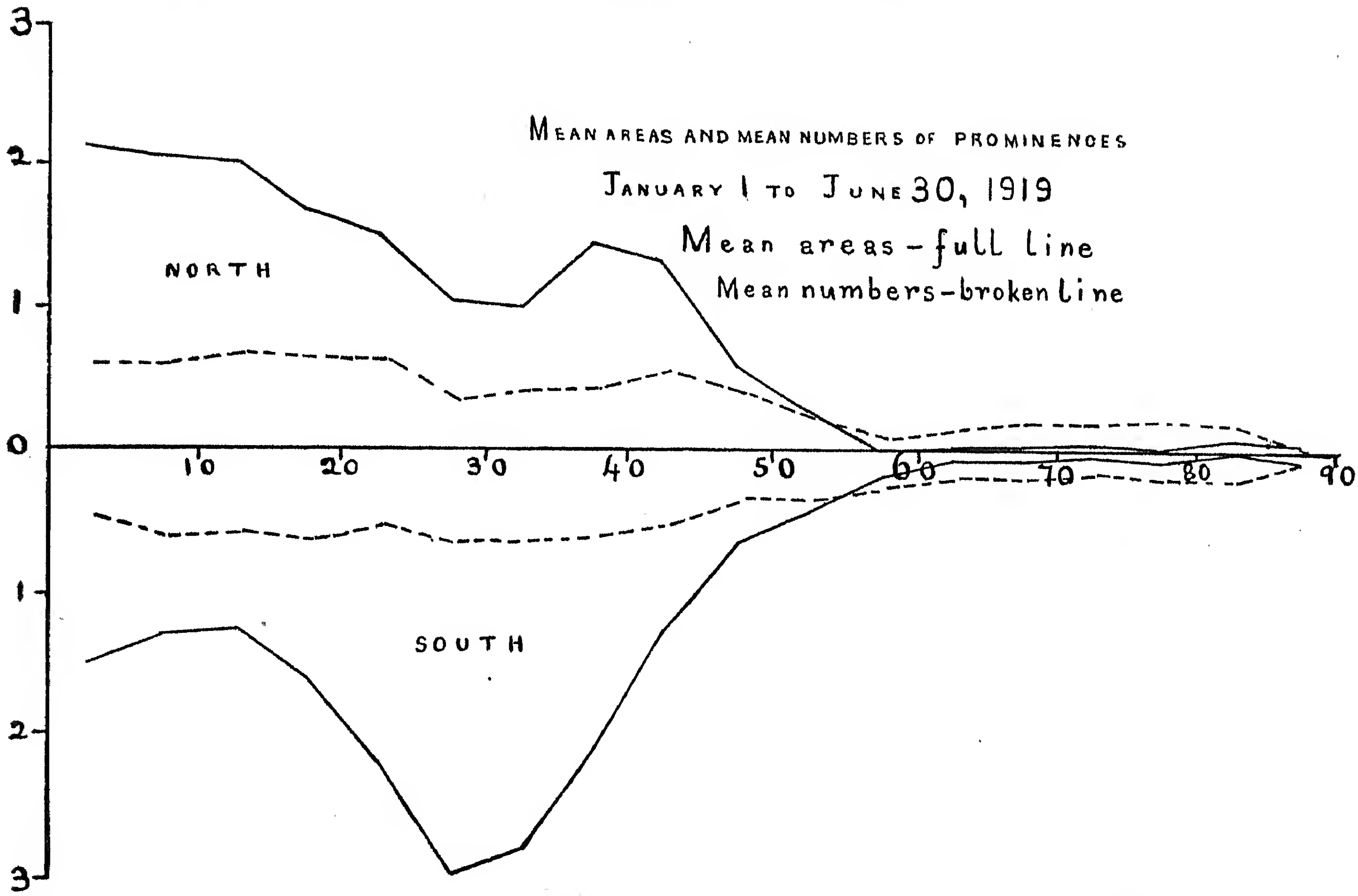
Kodaikanal Observatory.

BULLETIN No. LXI.

SUMMARY OF PROMINENCE OBSERVATIONS FOR THE FIRST HALF OF THE YEAR 1919.

The distribution of prominences observed and photographed during the half-year ending June 30th, 1919, is represented in the following diagram, in which the full line gives the mean daily areas and the broken line the mean daily numbers for each zone of 5° of latitude. The ordinates represent tenths of a square minute of arc for the full line and numbers for the broken line. The means are corrected for incomplete or imperfect observations, the total of 174 days being reduced to 159 effective days.



The distribution in the southern hemisphere has been almost identically the same as during the latter half of 1918, the only notable change indicated being the suppression of a feeble activity near the south pole which was maintained until the end of 1918. In the north there has been a transfer of activity from the zone 25°—35° to 35°—45°, and a considerable increase between the equator and latitude 20°.

The mean daily areas and numbers corrected for imperfect observations are given below :—

	Mean daily areas (square minutes).	Mean daily numbers.
North	1·55	6·86
South	1·81	6·78
Total ...	3·36	13·64

This indicates for areas a slight increase in the northern hemisphere and a decrease in the south compared with the previous half year. For numbers there is a general decrease amounting to 15 per cent. The excess of area in the south noted in 1918 has been maintained although numbers are nearly equally divided between north and south. The southern prominences were on the average slightly brighter than the northern.

The monthly, quarterly, and half-yearly areas and numbers, and the mean height and extent of the prominences are given in table I. The unit of area is 1 square minute of arc.

TABLE I.—ABSTRACT FOR THE FIRST HALF OF 1919.

Month.	Number of days (effective).	Areas.	Numbers.	Daily Means		Mean height.	Mean extent.
				Areas.	Numbers.	″	°
January	29	87·7	467	3·02	16·1	30·6	2·58
February	28	96·8	434	3·46	15·5	28·1	2·68
March	30	110·9	458	3·69	15·3	27·8	2·82
April	26	98·0	316	3·77	12·2	32·5	3·55
May	25	84·8	264	3·39	10·6	26·1	3·56
June	21	56·1	230	2·66	11·0	27·9	3·29
First quarter	87	295·4	1359	3·39	15·6	28·9	2·68
Second quarter	72	238·9	810	3·32	11·3	29·1	3·48
First half-year	159	534·3	2169	3·36	13·6	29·0	2·99

This table has been modified by the inclusion of prominence areas, and the suppression of a column giving the total number of days of observation. It is considered that the mean monthly areas will give a truer index of the prominence activity than the mean numbers. Although the mean areas of prominences show a very slight increase, there has been a general decrease in mean numbers, height, and extent on the limb compared with the last half of 1918.

A prominence remarkable for its size was photographed on May 28 and 29 extending over 40 degrees of the south-eastern limb, between latitude $-10°$ and $-50°$, and covering an area of 12 square minutes. The prominence became partially separated from the limb on the 29th and the main portion ascended slowly and became dissipated in space between $16^h\ 33^m$ I.S.T. ($11^h\ 03^m$ G.C.T.), on the 29th and $7^h\ 44^m$ I.S.T. ($2^h\ 14^m$ G.C.T.), on the 30th. This was the final stage of an apparently stable prominence which had been recorded as an absorption marking early in the month, crossing the central meridian on May 9 and appearing on the western limb between latitude $-15°$ and $-43°$ on May 16.

Distribution east and west of the sun's axis.

The distribution of the prominences east and west of the sun's axis is similar to that observed in the previous half year, areas showing an eastern preponderance and numbers a western. The figures are given in the table below :—

1919 January to June.	East.	West.	Percentage east.
Total number observed	1038	1131	47·85
Total areas in square minutes	283·9	250·5	53·13

There is no marked difference in the mean brightness of eastern or western prominences.

Metallic Prominences.

An unusual number of metallic prominences was recorded during the half year, the total being 121, whilst during the whole of 1918 only 65 were observed. This large increase may be in part due to increased vigilance in searching for bright lines in prominences, but there seems to be no doubt that the sun has been more active than usual in the eruption of metallic vapours characteristic of the lower chromosphere. The sodium magnesium and enhanced lines of iron have usually been observed but several other iron lines have also been noted together with a few lines of chromium and titanium, and the barium line 4934·2.

It may be noted that the occurrence of a large number of metallic prominences synchronises with a period of great magnetic activity as recorded by the Observatory magnetographs.

Details of the metallic prominences are given in the following table :—

TABLE II.—LIST OF METALLIC PROMINENCES OBSERVED AT KODAIKANAL, JANUARY TO JUNE 1919.

Date.		Hour I.S.T.	Base.	Latitude.		Limb.	Height	Lines.
				North.	South.			
1919.		H. M.	°	°	°		″	
January	2	9 45	3		29·5	W	30	b_1, b_2, b_3. 5316·8.
	3	8 36	9		7·5	E	35	D_1. D_2, b_1, b_2.
	4	8 34	3	22·5		E	30	b_1, b_2, b_3, 5316·8.
	4	8 48			15	W	55	D_1, D_2, b_1, b_2, b_3, b_4, 5316·8.
	6	8 43			11·5	W	40	D_1, D_2, b_1, b_2, b_3, b_4, 5316·8.
	7	8 32	7		16·5	W		D_1, D_2, b_1, b_2, b_3, b_4, 5316·8, 4924·1, 6677.
	11	11 25	12		32	E	100	D_1, D_2, b_1, b_2, b_3, b_4. Whole prominence seen in these lines.
	12	10 5	2	13		E	30	4924·1, 5016, 5018·6, b_1, b_2, b_3, b_4, 5316·8, D_1, D_2, 6677 and 7065 very bright over whole height; 5197·7, 5234·8, 5276·2 slightly bright.
	12	10 29	17		28·5	E	95	D_1, D_2, b_1, b_2, b_3, b_4 bright over lower part (50″).
	14	9 0	2		8	E	50	D_1, D_2, b_1, b_2, b_3, b_4, 5316·8, 6677, 7065 very bright.
	14	8 46	3		14·5	W	40	D_1, D_2, b_1, b_2, b_3, b_4, 5316·8.
	14	8 41	11	11·5		W	100	D_1, D_2, b_1, b_2, b_3, b_4, 5316·8, 5018·6, 4924·1 slightly bright.
	16	10 45		10		W	30	D_1, D_2, b_1, b_2, b_3, 5316·8.
	17	9 30			79·5	E		b_1, b_2, b_3, 5316·8.
	17	9 20			85	W		D_1, D_2, b_1, b_2, b_3, b_4, 5316·8, 6677.
	17	9 0			72·5	W		D_1, D_2, b_1, b_2, b_3, 5316·8, 6677.
	17	10 20	2	7		W	60	6677, 7065, D_1, D_2, b_1, b_2, b_3, b_4, 5316·8, 4924·1, 4922, 5016, 5018·6. The whole prominence was seen in the first nine lines.
	17	10 52		17		W		D_1, D_2, b_1, b_2.
	17	10 53		18		W		D_1, D_2, b_1, b_2, b_3, b_4, 5316·8.
	18	9 30	1	15·5		W	60	D_1, D_2, b_1, b_2, b_3, b_4, 5316·8.
	18	9 15		27		W		b_1, b_2, b_3.
	19	8 50			17	W	35	D_1, D_2, b_1, b_2, b_3, b_4, 5316·8.
	19	9 21	3	12·5		W	60	D_1, D_2, b_1, b_2, b_3, b_4, 5316·8.
	20	9 30		Equator.		E	40	D_1, D_2, b_1, b_2, b_3.
	25	9 58	4		32	W	50	D_1, D_2, b_1, b_2, b_3, b_4.
	25	8 46	6		1	W	45	D_1, D_2, b_1, b_2, b_3, b_4.
	26	9 50	1·5		34	W		D_1, D_2, b_1, b_2, b_3.
	28	12 0			41	E	70	D_1, D_2, b_1, b_2, b_3, b_4, 5316·8.
	30	9 51		10		E	15	D_1, D_2, b_1, b_2, b_3, b_4, 5316·8, 6677.
	30	9 40	7		4·5	E	80	D_1, D_2, b_1, b_2, b_3, b_4, 5316·8, 6677.
	30	9 20	4		14	E	85	D_1, D_2, b_1, b_2, b_3, b_4.
	30	9 12			83·5	E		D_1, D_2, b_1, b_2, b_3, b_4, 5316·8.
	30	8 54			80	W		D_1, D_2, b_1, b_2, b_3, b_4, 5316·8.
	30	10 7	3		39	W	10	D_1, D_2, b_1, b_2, b_3, b_4.
	31	9 55	13	14·5		E	120	D_1, D_2, b_1, b_2, b_3, b_4.
	31	9 30	1		39	E	50	D_1, D_2, b_1, b_2, b_3, b_4.

Date.		Hour I.S.T.		Base.	Latitude.		Limb.	Height.	Lines.
					North.	South.			
1919.		H.	M.	°	°	°		"	
February	1	9	44	8	14		E	65	7065. 6677, D_1, D_2, b_1, b_2, b_3, b_4, 5316·8, 5016, 5018·6, 4924·1
	1	9	13	5		17·5	E	90	D_1, D_2, b_1, b_2, b_3, b_4, 5316·8.
	1	9	0	1		42	E	15	D_1, D_2, b_1, b_2, b_3, b_4, 5316·8.
	4	9	37			20	E		D_1, D_2 b_1, b_2, b_3, b_4, 5316·8.
	4	9	24	2		37	E		D_1, D_2, b_1, b_2, b_3, b_4, 5316·8.
	6	10	0		15		E	25	D_1, D_2, b_1, b_2, b_3, b_4, 4924·1, 5316·8, 6677, 7065.
	7	10	20	5	1·5		E	40	D_1, D_2, b_1, b_2, b_3, b_4.
	8	8	32	11	8·5		E	35	D_1, D_2, b_1, b_2, b_3, b_4, 6677, 7065.
	9	9	37	12	5		E	80	D_1, D_2, b_1, b_2, b_3, b_4, 5316·8.
	10	9	4		16		W	40	D_1, D_2, b_1, b_2, b_3, b_4.
	13	10	35		5·5		W	80	4924·1 b_1, b_2, b_3, b_4, 5016, 5316·8, 5276·2, D_1, D_2, 6677, 7065. Whole prominence seen in Na and Mg.
	14	8	55		71·5		E		D_1, D_2, b_1, b_2, b_3.
	14	9	30	8	15		W	180	7065. 6677, D_1, D_2, b_1, b_2, b_3, b_4, 5316·8, 5276·2, 5018·6, 5016, 4924·1.
	15	8	46	12	13		W	85	4924·1, 5018·6, b_1, b_2, b_3, b_4, 5234·8, 5316·8, D_1, D_2, 6677, 7065.
	16	9	45	2	61		E	15	4924·1, b_1, b_2, b_3, b_4, 5316·8, D_1, D_2.
	16	11	0		16		E	30	4924·1, b_1, b_2, b_3, b_4, 5316·8, D_1, D_2.
	17	8	56	2		21	W	10	D_1, D_2, b_1, b_2, b_3, b_4, 5316·8.
	20	10	2	17	38		E	120	D_1, D_2, b_1, b_2, b_3, b_4.
	20	9	15			38·5	E		D_1, D_2, b_1, b_2, b_3, 5316·8.
	23	9	5	3	43		E	55	D_1, D_2, b_1, b_2, b_3, b_4, 5316·8.
	23	9	40	12	11		W	60	D_1, D_2, b_1, b_2, b_3, b_4, 5316·8,
	24	8	49	2	11		E	10	D_1, D_2, b_1, b_2, b_3, b_4, 5316·8, 6677.
	24	8	34	28	7		W	80	4924·1, 4934·2, 5016, 5018·6, b_1, b_2, b_3, b_4, 5197·7, 5204·8, 5206·2, 5208·8, 5215·3, 5218·2 5269·7, 5270·5, 5276·2, 5316·8, 5324·3, 5328·1 5363·0, 5535·1, D_1, D_2, 6677, 7065.
	25	9	31	15		30	E	120	D_1, D_2, slightly bright.
	26	9	40		10		E	15	D_1, D_2, b_1, b_2, b_3, b_4, 5316·8, 6677, 7065.
	26	9	46			7	E	35	D_1, D_2, b_1, b_2, b_3, b_4, 5316·8.
	26	8	55			64	W		D_1, D_2 b_1, b_2, b_3, b_4, 4924·1, 5016, 5316·8.
	27	8	38	3	18·5		E	25	D_1, D_2, b_1, b_2, b_3, b_4, 5316·8, 6677, 7065.
March	2	9	22	2		55·5	W	25	D_1, D_2, b_1, b_2, b_3, b_4, 5197·7, 5276·2, 5316·8.
	2	9	28	2		45·5	W	50	D_1, D_2, b_1, b_2, b_3, b_4, 5276·2, 5316·8.
	5	9	30		28·5		W	15	D_1, D_2, b_1, b_2, b_3, b_4, 5316·8,
	6	9	45	5	5·5		E	60	4924·1, 5018·6, 5316·8, b_1, b_2, b_3, b_4, D_1, D_2, 6677, 7065.
	7	9	50	3	20·5		E	90	D_1, D_2, b_1, b_2, b_3, b_4, 5316·8, 6677, 7065.
	7	10	0		13		E	10	D_1, D_2, b_1, b_2, b_3, b_4, 5316·8, 6677, 7065.
	8	8	36	8		6	W	70	4924·1, 5016. 5018·6, b_1, b_2, b_3, b_4, 5197·7, 5234·8, 5276·2, 5284 2, 5316·8, 5363·0, 5535·1, D_1, D_2, 6677,7065.
	9	9	10			20	E	15	D_1, D_2, b_1, b_2, b_3, b_4, 5316·8.
	10	8	38	20	10·5		E	60	D_1, D_2, b_1, b_2, b_3, b_4, 5316·8. 6677, 7065.
	10	8	46			20	E	40	D_1, D_2, b_1, b_2, b_3, b_4, 5316·8.
	11	9	0	11	8·5		W	125	D_1, D_2, b_1, b_2, b_3, 5316·8.
	13	10	2	5		30	W	40	4924·1, 5016, 5018·6, b_1, b_2, b_3, b_4, 5316·8, D_1, D_2, 6677, 7065.
	13	9	48		19		W	10	D_1, D_2, b_1, b_2, b_3, b_4, 4924·1, 5016, 5316·8, 6677.
	19	10	11	7	11·5		W	35	4924·1, 5016, 5018·6, b_1, b_2, b_3, b_4, 5316·8, 6677.
	23	10	15			13	E	75	D_1, D_2, b_1, b_2, b_3, b_4, 5316·8, 6677, 7065.
	23	10	25			30	E	35	D_1, D_2, b_1, b_2, b_3, b_4, 5316·8.
	24	8	49		6		E	80	D_1, D_2, b_1, b_2, b_3, b_4, 5316·8, 5016, 6677, 7065.
	25	9	48	19	4·5		E	95	D_1, D_2. b_1, b_2, b_3.
	25	10	0	13		27·5	E	85	D_1, D_2, b_1, b_2, b_3, b_4, 6677.
	26	8	34	2		20	E	10	4924·1, 5016, 5018·6, 5316·8, b_1, b_2, b_3, b_4, D_1, D_2, 6677.
	26	8	30	4		29	E	60	D_1, D_2, b_1, b_2.
	27	9	55	4	20		E	20	4924·1, 5016, 5018·6, b_1, b_2, b_3, b_4, 5316·8, D_1, D_2, 6677, 7065.

Date.		Hour I.S.T.	Base.	Latitude. North.	Latitude. South.	Limb.	Height.	Lines.
1919.		H. M.	°	°	°		"	
March	28	8 37	13	28·5		E	30	D_1, D_2, b_1, b_2.
	29	9 15		32		E	30	D_1, D_2, b_1, b_2, b_3, b_4, 5316·8.
	30	9 45		9		E	10	D_1, D_2, b_1, b_2, b_3, b_4, 5316·8.
	31	8 46	2	10		E	60	4924·1, 5016, 5018·6, b_1, b_2, b_3, b_4, 5197·7, 5234·8, 5276·2, 5316·8, 5363·0, 5535·1, D_1, D_2, 6677, 7065.
April	1	9 16			10	W	15	D_1, D_2, b_1, b_2, b_3.
	3	9 51	4	17		E	15	D_1, D_2, b_1, b_2, b_3, b_4, 5316·8, 6677, 7065.
	3	9 25	1		9·5	W	30	6677, 7065, bright over top.
	4	8 28			8	W	25	D_1, D_2, b_1, b_2, b_3, b_4, 5316·8.
	5	9 50		25		E	50	D_1, D_2, b_1, b_2, b_3, b_4, 5316·8, 6677, 7065, 4924·1.
	14	8 53		10		W	15	4924·1, 5016, 5018·6, b_1, b_2, b_3, b_4, 5316·8, D_1, D_2, 6677, 7065.
	16	8 33	7		26·5	W	40	D_1, D_2, b_1, b_2, b_3, b_4, 5316·8, 5018·6, 4924·1.
	17	9 5	3		9·5	W	20	4924·1, 4922·0, 5016, 5018·6, b_1, b_2, b_3, b_4, 5197·7, 5204·8, 5206·3, 5208·5, 5226·7, 5234·8, 5266·8, 5270·6, 5316·8, 5328·2, D_1, D_2, 6677, 7065.
	20	8 21	8		20	E	25	D_1, D_2, b_1, b_2, b_3, b_4, 5316·8.
	23	8 18		19		E	45	D_1, D_2, b_1, b_2, b_3, b_4, 5316·8.
	23	8 33	10	7		W	55	4922·0, 4924·1, 4934·2, 5016, 5018·6, b_1, b_2, b_3, b_4, 5197·7, 5234·8, 5276·2, 5284·2, 5316·8, 5363·0, 5535·1, D_1, D_2, 6677, 7065.
	24	8 38		{24, 19}		E	90	D_1, D_2, b_1, b_2, b_3, b_4, 5316·8.
	24	8 41	2		12	E	25	4924·1, 5016, 5018·6, b_1, b_2, b_3, b_4, 5197·7, 5204·8, 5206·3, 5208·5, 5222·1, 5234·8, 5269·8, 5276·2, 5284·2, 5316·8, 5328·1, 5363·0, 5371·6, 5397·3, 5404·4, 5405·9, 5424·3, 5429·9, 5447·1, 5535·1, D_1, D_2, 6677, 7065.
	28	9 45		10		E	30	D_1, D_2, b_1, b_2, b_3, b_4, 5316·8.
	29	9 26		15		W	60	D_1, D_2, b_1, b_2, b_3, b_4, 5316·8, 6677.
May	1	9 15		15		E	25	D_1, D_2, b_1, b_2, b_3, b_4, 5316·8.
	3	10 20	2	16		E	15±	D_1, D_2, b_1, b_2, b_3, b_4, 5316·8.
	8	9 14	2		17	W	10	D_1, D_2, b_1, b_2, b_3, b_4, 5316·8.
	12	7 56	2	20		E	10	7065, 6677, D_1, D_2, b_1, b_2, b_3, b_4, 5316·8, 4924·1.
	14	9 0			21	E	30	7065, D_1 D_2, b_1, b_2, b_3, b_4, 5316·8, 4924·1.
	15	9 52	2		3	E	25	7065, 6677, D_1, D_2, b_1, b_2, b_3, b_4, 5316·8, 4924·1.
	15	9 30	7	17·5		W	30	D_1, D_2, b_1, b_2, b_3, b_4, 5316·8.
	16	11 0	12	26		W	20	D_1, D_2, b_1, b_2, b_3, b_4.
	21	9 8	8	19		E	45	D_1, D_2, b_1, b_2, b_3, b_4.
	28	8 50	35	4·5		E	50	D_1, D_2, b_1, b_2, b_3, b_4, 5316·8.
	28	8 56			16	W		D_1, D_2, b_1, b_2, b_3, b_4, 5316·8.
June	1	8 33			18	E	25	D_1, D_2, b_1, b_2, b_3, b_4, 5316·8.
	8	8 51		13		E	10	D_1, D_2, b_1, b_2, b_3, b_4, 5316·8, 6677.
	8	8 58	5	7·5		W	25	4924·1, 5016, b_1, b_2, b_3, b_4, 5197·7, 5234·8, 5276·2, 5284·2, 5316·8, D_1, D_2, 6677.
	23	9 33	11		26·5	W	20	D_1, D_2, b_1, b_2, b_3, b_4, 5316·8, 5016, 6677, 7065.
	23	9 34	4		15	W	15	D_1, D_2, b_1, b_2, b_3, b_4, 5316·8.

The metallic prominences recorded above were distributed in latitude as follows :—

—	1° to 30°.	31° to 60°	61° to 90°	Mean latitude.	Extreme latitudes.
				°	° °
North	58	3	2	16·6	1, 71·5
South	40	11	6	27·6	1, 85
Equator	1	...	...	...	

Sixty-nine were in the eastern limb or 57 per cent of the whole.

Displacements of the hydrogen lines.

Particulars of the displacements observed in the chromosphere and prominences are given in the following table :—

TABLE III.

Date.	Hour I.S.T.		Latitude.		Limb.	Displacement.			Remarks.
			North.	South.		Red.	Violet.	Both ways.	
1919.	H.	M.	°	°		A	A	A	
January 2	9	34	2		E		Slight		At top.
2	9	38	22·5		W	Slight			Do.
3	8	36		3	E		0·5		At base.
3	8	36		12	E	1			At top.
3	8	22	66		W		1·5		
4	8	42	66		E	Slight			
4	8	35	24		E		Slight		
4	8	31		1·5	E	1			No prominence.
4	8	48		15	W		0·5		
6	8	43		11·5	W	0·5			At top.
9	10	15	67		E		0·5		At base.
9	11	31		35	E		Slight		
9	11	0	27·5		W	Slight			At top.
10	9	28		39	W	2			
10	9	22		32	W	Slight			
11	10	24	6		E	Do.	3		
11	11	6		47	E		2		
11	10	15		78	W	Slight	3		To red at base ; to violet at top.
11	9	58	4		W		Slight		
11	9	45	64·5		W	0·5			
12	9	54	74·5		E		Slight		No prominence.
12	10	55	13		E	2			
13	8	25		24	E		Slight		At base.
13	8	20		78	E	Slight			No prominence.
13	8	35		37	W		Slight		
14	8	33	81		E		Do.		
14	9	1		33	E	0·5			
15	10	37		9·5	E		2		
15	10	14		64	W		1		
15	11	12		36·5	W	1			
15	11	15		16·5	W	3			
15	11	22		5·5	W	1			
15	11	27	10		W	1			
16	11	10	84		E		Slight		
16	11	13	74·5		E	Slight			
16	11	15	64·5		E	Do.			
16	11	17	55·5		E	Do.	Slight		
16	11	34	4		E	Do.			
16	11	40	1·5		E		1		
16	11	40		2	E	1			
16	12	0		55·5	E	Slight	Slight		
16	8	18		57	W	Do.			
16	9	53	10		W	1	0·5		
17	10	2		32	E	Slight			
17	9	27		42	E			Slight	
17	9	47		58·5	E		Slight		
17	9	20		85	W			Slight	
17	9	0		72·5	W		1		
17	10	56	4		W	Slight			At top.
17	10	5	7		W	3	2		At 10^h 20^m C was displaced 4 A to red and 2 A to violet, and D_3 was displaced 4 A to red but only 1 A to violet.
17	11	56	45		W		Slight		
18	10	34		34	E		1		
18	9	55		44	W	Slight			
18	9	45		22	W	Do.			
18	9	30	15·5		W			Slight	
18	9	15	27		W	2			
19	8	48		25	W	Slight			
20	9	30	Equator.		E		2		

Date.		Hour I.S.T.		Latitude.		Limb.	Displacements.			Remarks.
				North.	South.		Red.	Violet.	Both ways.	
1919.		H.	M.	°	°		A	A	A	
January	20	9	42		9·5	E		1		
	20	9	42		13	E			1	
	21	10	33		11·5	E	Slight	Slight		To red at base ; to violet at top.
	21	10	45		30·5	E	Do.			
	21	10	11		85	W	Do.			At base.
	21	10	3		34	W	Do.			
	21	9	45	39		W		Slight		
	21	9	40	47		W	Slight			
	21	9	19	78		W		Slight		
	23	9	18	84		E	2			
	23	9	13	80		E	Slight	1·5		To red at top ; to violet at base.
	23	9	50		29	W		Slight		
	23	9	38		5	W	1·5			At top.
	23	9	32	16		W	Slight			Do.
	23	9	21	44·5		W	1			
	24	10	39	81		E	Slight			
	24	10	13		14	E		Slight		
	24	9	58		73	E	Slight			
	24	9	58		75	E	Do.			
	24	9	53		76·5	W	Do.			
	24	11	4		21·5	W		1		
	24	10	55		17	W	3	1		To red at top ; to violet at base.
	25	10	5	12		E	Slight			
	25	9	48		13	W	Do.			
	25	9	34	11		W	0·5			
	25	9	22	2		W	1			
	25	9	13	46·5		W	1·5			
	25	9	4	71		W		2		
	25	9	57	77·5		W	2			
	26	10	5	81		E	Slight			
	26	8	54	71·5		E		Slight		
	26	9	39		11	W		Do.		
	26	9	10	25		W	1			
	26	9	5	42		W	Slight			At top.
	26	9	5	35·5		W	1			Do.
	27	8	36		80·5	W		Slight		At top ; not seen at 8^h 45^m.
	28	12	0		41	E		Do.		
	28	11	18	33		W	1			
	28	10	58	77		W	Slight			
	30	9	40		4·5	E	2			At top.
	30	9	1		83·5	E		Slight		
	30	8	54		80	W	Slight	1·5		To red at base ; to violet at top.
	30	8	52		73	W		Slight		
	30	11	26	5		W	2			
	31	9	4	10·5		E	2			
February	1	8	50		76·5	E	Slight			
	1	10	45	5		W		Slight		
	3	8	54	69		E		1·5		Slight over lower part and 1·5 at top.
	3	9	15	79·5		W	3			Whole prominence displaced.
	4	9	40		11	E	1·5			
	4	10	35		36	W		Slight		
	5	9	14	83·5		Axis			Slight	
	5	9	11	52·5		E		0·5		
	5	9	34		21	E	4			
	5	9	45		59·5	W	Slight			
	5	9	26		24	W	0·5			
	5	9	21	8		W	0·5			
	5	9	21	7		W		Slight		
	5	9	17	50		W	0·5			
	5	9	15	75·5		W	Slight			
	6	9	11	68		E	Do.			
	6	10	0	15		E	1·5			
	6	9	34		46·5	W	Slight			
	6	9	30	26		W	Do.			At top.
	6	9	18	81		W	Do.			
	7	10	0	9		E	Do.			
	7	10	37		57·5	W	1·5			

Date.		Hour L.S.T.		Latitude.		Limb.	Displacements.			Remarks.
				North.	South.		Red.	Violet.	Both ways.	
1919.		H.	M.	°	°		A	A	A	
February	7	9	35	16·5		W	1·5	Slight		To red at top ; to violet at base.
	7	9	16	69		W	Slight			
	8	8	32	8·5		E	Do.			
	8	11	32	12		W		Slight		
	9	9	37	5		E	1	2		To red at base ; to violet at top.
	9	9	8		35	E	1			
	9	8	56		80·5	E	Slight			
	9	8	53		74·5	W		Slight		
	9	8	51		69·5	W		Do.		
	9	10	10	44·5		W		1		
	9	10	13	79·5		W		Slight		
	10	9	16		10	E	2			No prominence.
	10	9	20		61·5	W	Slight			
	10	9	4	16		W		Slight		
	11	9	0		45·5	W	0·5			
	13	9	38		20	E	1			
	13	9	22		77·5	W		1		
	13	10	35	16		W		0·5		
	13	10	44	38·5		W	1			
	14	8	48	69		E	Slight			
	14	10	27		76	W		Slight		
	14	9	3	2		W		Do.		
	14	9	3	6		W	Slight			
	14	9	55	15		W	3	3		
	15	8	42		3	W		Slight		
	15	8	46	19		W		1		At base.
	16	9	35	61		E		Slight		
	16	10	18	44·5		E	Slight			
	16	10	20	34·5		E		1		
	16	10	28	20		E	1			
	16	10	50		8·5	E	1			
	16	10	55		30	E	2			
	17	8	42		36·5	E	Slight			
	17	8	40		58·5	E	Do.			
	17	8	38		80	E		Slight		
	17	8	43		81·5	E	Slight			
	17	8	58	8·5		W		2		No prominence.
	18	9	28		58·5	E		Slight		
	18	9	20	25		W	Slight			
	19	9	5	35·5		E	2			
	19	9	13	63		W	Slight			
	19	9	10	82·5		W		Slight		
	20	10	2	38		E	2			
	20	9	15		38·5	E	Slight	1		To red at top ; to violet at base. Not seen at 9h 25m.
	20	8	53		59·5	W	1			
	20	9	55		54·5	W		Slight		
	20	9	40	10		W		2		
	21	9	38	69		W	Slight			
	23	9	20	76		E		Slight		
	23	9	17	72·5		E		Do.		
	23	8	56	62		E		Do.		
	23	9	40	17		W	1·5	1		To red at top ; to violet at base.
	24	8	49	11		E			Slight	Displacements 2 A to violet and slightly to red at 8h 50m.
	25	8	54	66		E		Slight		
	25	8	54	65		E	Slight			
	25	8	52	41·5		E	0·5	Slight		To red at top ; to violet at base.
	25	9	8	12		E	2			
	25	9	9		2	E		Slight		
	25	9	31		30	E	1			At top.
	26	9	40	10		E	Slight	Do.		To red at base ; to violet at top.
	26	9	12		32	E	Do.			At base.
	26	9	10		35	E		Slight		
	26	9	0		81	E		Do.		
	26	8	50		64	W	1·5	1		To red at base ; to violet at top.
	26	10	10	40·5		W		Slight		
	26	10	11	80		W	Slight			
	27	8	43	52·5		E		Slight		

Date.		Hour I.S.T.		Latitude.		Limb.	Displacements.			Remarks.
				North	South.		Red.	Violet.	Both ways.	
1919.		H.	M.	°	°		A	A	A	
February	27	8	50	47·5		E	Slight			
	27	8	48	37·5		E		1		
	27	9	38	18·5		E	Slight	2		To red at base; to violet at top. The displacement was 2 A to red and 5 A to violet at 9h 44m.
	27	9	27		39	W	Slight			At top.
	27	9	18	35·5		W	Do.			
	27	9	9	49·5		W	3	2		To red at base; to violet at top.
	28	8	38		44·5	W		0·5		
	28	8	44	41·5		W		Slight		
March	1	8	47		6	E	Slight			No prominence.
	1	8	51		53·5	E	Do.			Do.
	1	8	42		48·5	W		Slight		
	1	8	34	54·5		W		1		
	2	10	7		9	E	Slight			
	2	10	0		38·5	E	Do.			
	2	9	45		65	E	Do.			
	2	9	40		82·5	W	Do.			
	2	9	5		65	W		Slight		
	2	9	22		55·5	W		2		At top.
	2	9	28		45·5	W	Slight			At base.
	3	8	25	81		E	Do.			
	3	8	39	37		E	Do.			At base.
	4	9	8	70·5		E	1			
	4	9	6	60		E	Slight			
	4	9	27	43·5		E		0·5		Not seen at 9h 28m.
	4	9	40		24	E	0·5	1		Extends from −22° to —26°.
	4	9	46		77	E	1			
	4	9	23		51·5	W	0·5			
	4	9	12	70·5		W	1			
	4	9	12	74·5		W	0·5			
	5	11	3		21	E	2			
	5	11	3		23	E	1·5			
	5	9	21		64	E	Slight			
	5	9	18		81·5	E	1			
	5	9	15		83	E		Slight		
	5	8	55		38·5	W	1			At top.
	5	11	15		16·5	W		Slight		
	5	9	30	28·5		W	1	2		To red at top; to violet at base.
	5	11	38	57·5		W	1			
	6	8	50	67		E		Slight		
	6	8	56	47·5		E	Slight			
	6	9	31	38·5		E	2	1		To violet at base; to red at top.
	6	9	33	19		E	Slight			
	6	9	45	5·5		E	1	Slight		To red at top; to violet at base.
	6	9	23		60	W		Do.		
	6	9	16	8·5		W	1			At top.
	6	9	10	30		W	0·5			
	6	9	6	58·5		W		0·5		
	6	9	4	73·5		W		Slight		
	6	9	2	82		W		Do.		
	7	9	50	19		E	1			
	7	10	0	13		E	1·5			
	7	9	30		31	E	Slight			At base.
	7	9	24		37·5	E	1·5			
	7	9	15		75·5	E		1		
	7	8	58		72·5	W		Slight		
	7	8	52		55	W	Slight			
	7	10	10		5	W	2			
	7	10	20	70		W		Slight		
	8	8	45	39		E	Slight			
	8	8	36		6	W			Slight	
	9	9	25	16		E	Slight			
	9	9	25	11		E	1			
	9	9	10		20	E		1		
	9	9	4		44·5	E	Slight			
	9	9	0		61	E	Do.			
	9	8	44		67	W		Slight		

Date.		Hour I.S.T.		Latitude.		Limb.	Displacements.			Remarks.
				North.	South.		Red.	Violet.	Both ways.	
1919.		H.	M.	°	°		A	A	A	
March	9	8	42		63	W		Slight		
	9	9	50		31·5	W	2			
	9	10	8	6		W	2	3		
	9	10	11	62		W		Slight		
	10	8	37	18		E	Slight			
	10	8	38	10·5		E	4	0·5		To red at top ; to violet at base.
	10	8	46		20	E			Slight	
	10	8	31		30	W	Slight			At top.
	10	8	29		10	W	Do.			Do.
	11	8	42	50·5		E	1			
	11	8	42	47·5		E		Slight		
	11	9	24	18		E	0·5	Do.		
	11	8	19	3		E			0·5	
	11	9	17		23	W			0·5	
	11	9	17		27	W		1		
	11	9	17		32	W	1			
	11	9	0	10		W		1		
	11	9	0	2		W	1			
	12	10	0	70		E	Slight			
	12	10	35		81	E	Do.			
	12	10	37		70	W	Do.			
	12	9	4		43·5	W		Slight		
	12	9	7		34·5	W	2	1		
	12	11	0		10	W	Slight			
	13	9	6	77		E	1			
	13	8	52	65		E		Slight		
	13	8	54	59·5		E	1			
	13	9	0	43·5		E	1	Slight		
	13	10	33		54	W	1			
	13	10	2		20	W	1	1·5		To red at top ; to violet at base.
	13	9	14	73·5		W	1			
	14	9	40	73·5		E	Slight			
	14	9	20		13	E	1·5			
	14	9	12		45	E		Slight		
	14	9	4		82·5	W		Do.		
	14	8	56		59·5	W		2		
	14	9	45		33·5	W	Slight			
	15	8	39	78		E		1		No prominence.
	16	9	12		81	W	1·5			
	16	9	8		66·5	W	Slight			No prominence.
	16	9	0		60	W	Do.			
	16	10	10	11·5		W		Slight		
	16	10	15	36·5		W	2			
	16	10	17	64		W		Slight		
	18	9	10	68		E		Do.		
	18	8	50	59·5		E		Do.		
	18	8	56	54·5		E	Slight			
	18	9	3	44		E	Do.	1		To red at top ; to violet at base.
	18	9	13	83		W	1			
	19	10	11	14		W			1·5	
	19	10	6	69		W		1		
	21	9	8	11·5		E		1		
	21	9	7	5		E		2		
	21	9	3		45	E		Slight		No prominence.
	21	9	18	44·5		W	4			Only 1·5 A at 9h 32m.
	22	8	48	81		E		Slight		
	22	{ 9 9	10 35 }		18	E	3	6		Eruptive (C was displaced at many places the maximum amount being 3 A to red and 4 A to violet near base and 2 A to red and 2 A to violet over top at 9^h 10^m. The maximum amount near base was 6 A to violet at 9^h 25^m. At 9^h 35^m the displacements were 3 A to red and 3 A to violet near base and 3 A to red and 4 A to violet near top).
	22	8	55	12		W		Slight		
	23	9	7	82		E	Slight			

Date.		Hour I.S.T.		Latitude.		Limb.	Displacement.			Remarks.
				North.	South.		Red.	Violet.	Both ways.	
1919.		H.	M.	°	°		A	A	A	
March	23	9	2	69		E		Slight		
	23	8	52	57·5		E		1		
	23	9	50	19·5		E	1			
	23	10	0	Equator.		E	1·5			At base.
	23	10	15		13	E	2	1·5		To red at base ; to violet at top.
	23	10	25		23	E	2			At base.
	23	10	10		25	E	3			Do.
	23	9	24		27·5	W		1		
	23	9	22		17	W		0·5		
	23	9	20		11	W		0·5		At base.
	23	9	15	7		W	Slight			
	24	8	49	1·5		E	Do.			
	24	8	44		69	E	Do.			
	24	8	33		57·5	W	6	2		To red at top ; to violet at base. D_3 displaced only 4 A to red and 2 A to violet.
	25	8	50	43·5		E		1		
	25	9	40	4·5		E	Slight			
	25	9	2	40·5		W		Slight		
	26	8	34		20	E	Slight			
	26	8	25		38·5	W		Slight		
	27	9	13	65		E		Do.		
	27	9	5	51·5		E		Do.		
	27	9	55	17		E		1		At top.
	27	10	2		49·5	E	Slight			
	28	8	30		22	W			Slight	
	28	8	47	6		W			Do.	
	29	8	50	63		E		Slight		
	29	8	52	54·5		E	Slight			
	29	8	56	49		E	0·5	1		To red at top ; to violet at base.
	30	9	10	16		E		5		
	30	9	30	14		E		2		
	30	9	45	9		E	1			
	30	8	51		62	W	Slight			
	30	8	55		47·5	W		1		
	30	8	58		42·5	W	Slight			
	30	9	2		31·5	W		1·5		
	31	8	52	80		E		0·5		No prominence.
	31	8	46	8		E	Slight			
April	1	9	5	70		E		Slight		
	1	8	55	44		E		2		At base.
	1	8	55	41		E	1·5			At top.
	1	9	25		31	E		1·5		
	1	9	16		10	W		0·5		
	3	9	3	73		E	Slight			
	3	9	45	22		E		Slight.		
	3	9	25		11	W	Slight	1		To red at top ; to violet at base.
	3	9	12	19		W	Do.			No prominence.
	3	9	8	79		W		Slight		
	4	8	18		62·5	E	1			
	4	8	27		12	W		1		Over lower half of prominence.
	5	9	2	83		E		Slight		
	5	9	6	29		W		Do.		
	6	8	52		10	E	Slight			
	6	8	45	7		W		1		
	6	8	38	83		W	Slight			
	7	10	15	24·5		E	0·5	1		To red at base ; to violet at top.
	7	10	10		76	E		Slight		
	8	9	28	77		E			0·5	
	8	9	39	52·5		E		0·5		
	9	8	27		64·5	E		Slight		At top.
	9	8	35		42·5	W		Do.		No prominence.
	10	8	35		34	W			Slight	
	12	9	5		2·5	W		Slight		
	14	9	12		76	W	Slight			No prominence.
	14	8	54	3		W		Slight		

Date.	Hour I.S.T.		Latitude.		Limb.	Displacements.			Remarks.
			North.	South.		Red.	Violet.	Both ways.	
1919.	H.	M.	°	°		A	A	A	
April 14	8	52	16		W		Slight		At top.
16	8	35	11		W	Slight			
17	8	38	21		E		1		
17	9	5		10	W	2		3	In different places.
18	9	20		83·5	E		0·5		
20	8	21		20	E	Slight			
22	8	31	3		E	Do.			At top.
22	8	25	1		W			Slight	
23	8	33	4		W	0·5	1·5		
24	8	38	14		E		0·5		
24	8	41		12	E			1	
24	8	29		3	W		Slight		No prominence.
28	9	13	76·5		E		Do.		
28	9	26	42		E	Slight			
28	9	52		69·5	W	Do.			
29	9	26	6·5		W		1		
30	9	7	16·5		E	Slight			
May 1	9	18	44		E	Slight			
1	8	4	16		E	Do.			
1	9	0		1·5	E	Do.			
1	8	41		67	W		Slight		
2	8	25	55		E		Do.		
2	9	24		65·5	E		1		
2	8	40	4·5		W	3	1		To violet at base ; to red at top.
2	8	35	45		W	Slight			
2	7	56	66·5		W		Slight		At base.
3	9	49		11	E		1		
5	8	55	65·5		E		Slight		
6	9	40	20		W		Do.		
8	8	52	64		E		1		At base.
8	9	0	45		W	1			Do.
9	9	57	83		E		Slight		
9	9	10	67		E		Do.		
9	9	20		36	W	3			At base.
10	9	8		26	E	2			
11	11	12		37	W	Slight			
12	9	35	14·5		E	2	1		To red at base ; to violet at top.
12	9	32	11		E	2	1		Do.
12	9	23		46	E	Slight			
12	9	22		70	E		Slight		
12	9	20		77·5	W	Slight			No prominence.
13	9	42	2		E	1	2		To red at base ; to violet at top.
14	9	12	19		E	1·5			At top.
14	9	5		2	E		Slight		
14	8	51		27	E	2			At base.
14	8	42		60	W	Slight			
14	8	44		46	W	Do.			
14	9	27	66		W		Slight		
15	9	50		3	E	2	4		To red at base ; to violet at top.
15	9	5	31		W	Slight			
15	8	58	75		W		Slight		No prominence.
16	9	12	3·5		E	2	1·5		
18	8	58	73		E		Slight		No prominence.
18	8	44	27·5		W	2	2		To red at top ; to violet at base.
21	9	6		17	E		Slight		
21	9	12		38	W	Slight	Do.		To red at base ; to violet at top.
22	8	42	71		E		Do.		
22	8	51	24·5		E	Slight			
24	9	7		70	W	1·5	Slight		
27	10	28		85	W		1		
27	10	12	1		W	Slight			
27	10	9	31·5		W	1			At top.
28	8	52	64		E	0·5			
29	9	21		84	W		1		
30	7	44	73		E		Slight		
30	8	53		18	W	1	2		To red at base ; to violet at top.
31	9	45		7	E	2			

Date.		Hour. I.S.T.	Latitude.		Limb.	Displacements.			Remarks.
			North.	South.		Red.	Violet.	Both ways.	
1919.		H. M.	°	°		A	A	A	
May	31	9 36		20	E	Slight			
	31	9 34		25	E		Slight		At top.
	31	9 22		42	W	Slight			
	31	9 57		28	W	2			
June	6	10 48		12	W	Slight			
	8	8 58	7		W	Do.			
	9	8 49	14		E	2			
	9	8 46	7		W	Slight			At top.
	13	8 33		19	E	Do.			
	14	9 25		6·5	W	Do.			At south end.
	15	9 42		15	W		3		
	15	9 38	64		W		Slight		No prominence.
	16	8 38		15	W		Do.		
	17	9 17	21		W		Do.		
	18	9 7		70	E	1			No prominence.
	22	10 45	56		E	Slight			
	22	10 53	12·5		W		Slight		
	23	9 26		64	E	Slight			
	24	10 4	83·5		W	Do.			
	28	9 43	14		W	Do.			
	29	9 54		21·5	E		Slight		
	29	9 52		86	W	Slight			
	29	8 29		2·5	W			Slight	
	30	8 27		64	E		Slight		
	30	8 27	64		W		Do.		

The total number of displacements was 473, of which 2 were on the equator, and the rest were distributed as follows :—

Latitude.	North.	South.
1° to 30°	110	87
31° to 60°	60	71
61° to 90°	83	60
Total ...	253	218
East limb	238	
West limb	234	
Pole	1	

There were 276 displacements towards red and 227 towards violet. These include 49 occasions in which the displacement was to red and to violet in different parts of the same prominence. 19 of the displacements were both ways simultaneously.

Reversals and displacements on the disc.

185 bright reversals of the Hα line, 43 dark reversals of the D_3 line and 96 displacements of the Hα line were recorded. They were distributed as follows :—

	North.	South.	East.	West.
Bright reversals of Hα	110	75	102	83
Dark reversals of D_3	22	21	28	15
Displacements of Hα	57	39	41	55

All these figures are in excess as compared with the previous half year. 71 of the displacements were towards red, 19 towards violet and 6 both ways simultaneously.

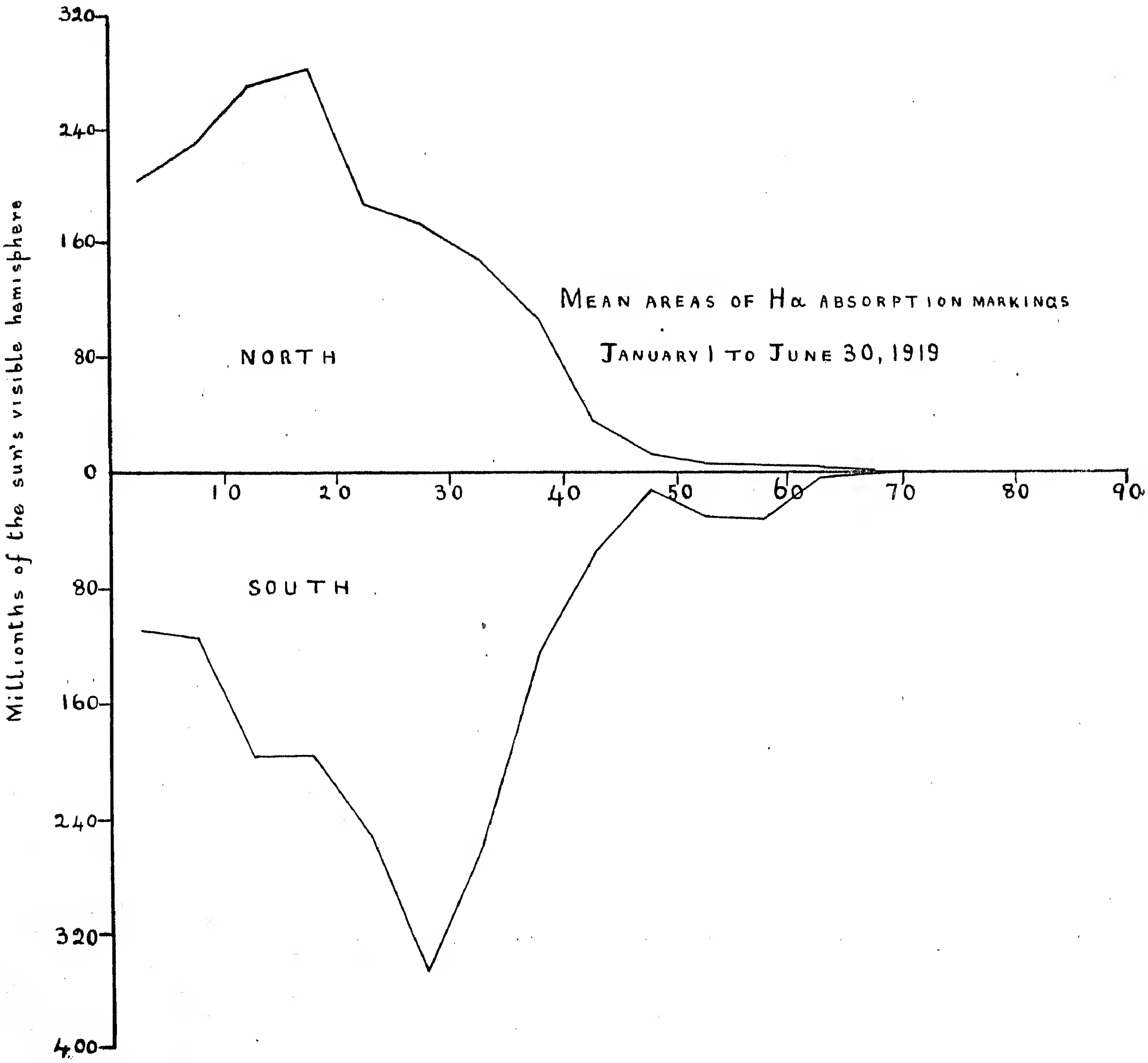
Prominences projected on the disc as absorption markings.

Photographs of the sun's disc in Hα light were obtained on 141 days counted as 132 effective days. The mean daily areas in millionths of the sun's visible hemisphere, corrected for foreshortening, and the mean daily numbers are given below :—

	Areas.	Numbers.
North	1668	10·0
South	1734	10·8
Total ...	3402	20·8

Both areas and numbers show an increase in the northern hemisphere, and a decrease in the south compared with 1918, as is shown also by the prominences at the limb. The total areas are slightly greater and numbers slightly less than were obtained for the previous half year ; this also is in agreement with the results for prominences at the limb.

The distribution of the absorption markings in latitude is shown in the accompanying diagram.



As in the case of prominences at the limb, the region of maximum activity shows a tendency to move towards the equator, more rapidly in the northern hemisphere than in the southern.

For the first time since 1916 the percentage of areas in the eastern hemisphere (49·25 per cent) is less than in the western. In the case of numbers the eastern percentage is 50·29.

KODAIKANAL OBSERVATORY,
12th August 1919.

J. EVERSHED,
Director, Kodaikanal and Madras Observatories.

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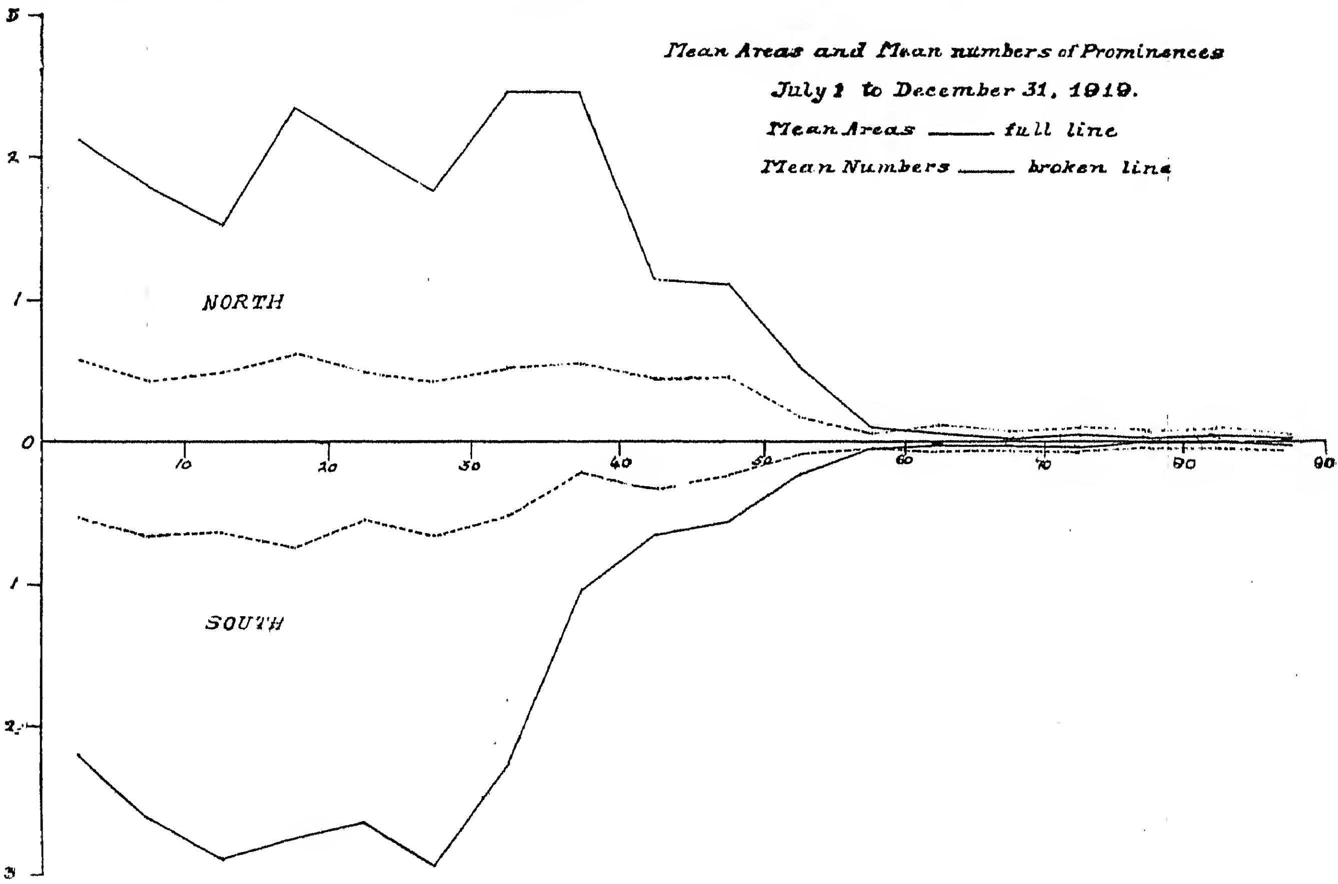
Kodaikanal Observatory.

BULLETIN No. LXII.

SUMMARY OF PROMINENCE OBSERVATIONS FOR THE SECOND HALF OF THE YEAR 1919.

The distribution of prominences observed and photographed during the half-year ending December 31st, 1919, is represented in the following diagram, in which the full line gives the mean daily areas and the broken line the mean daily numbers for each zone of 5° of latitude. The ordinates represent tenths of a square minute of arc for the full line and numbers for the broken line. The means are corrected for incomplete or imperfect observations, the total of 144 days being reduced to 115 effective days.



The distribution indicates, as compared with the previous half-year, a considerable increase of activity in the southern equatorial region. In the north, three zones of activity have developed with maxima as shown in the diagram.

The mean daily areas and numbers corrected for imperfect observations are given below :—

	Mean daily areas (square minutes).	Mean daily numbers.
North	1·96	5·78
South	2·09	5·54
Total ...	4·05	11·32

Areas show an increase of about 20 per cent over the previous half-year. This increase is somewhat greater for the northern hemisphere than for the southern. For numbers there is a general decrease amounting to 17 per cent. The excess of areas in the southern hemisphere is still maintained but numbers show a slight northern preponderance. The southern prominences were slightly brighter than the northern.

The monthly, quarterly and half-yearly areas and numbers, and the mean height and extent of the prominences are given in table I. The unit of area is 1 square minute of arc.

TABLE I.—ABSTRACT FOR THE SECOND HALF OF 1919.

Month	Number of days (effective).	Areas.	Numbers.	Daily Means Areas.	Daily Means Numbers.	Mean height. ″	Mean extent. °
July	15	56·4	163	3·76	10·9	31·4	3·02
August	22	79·8	185	3·63	8·4	37·6	3·85
September	15	57·3	169	3·82	11·2	32·9	3·63
October	22	99·1	289	4·51	13·1	34·0	3·26
November	17	70·8	213	4·15	12·5	34·0	2·96
December	24	102·5	283	4·27	11·8	36·1	3·15
Third quarter	52	193·5	517	3·72	9·9	34·0	3·50
Fourth quarter	63	272·4	785	4·32	12·5	34·7	3·14
Second half-year	115	465·9	1302	4·05	11·3	34·4	3·28

Although the mean numbers have diminished, the mean height and extent have increased resulting in an increase of the mean area.

Distribution east and west of the sun's axis.

Both areas and numbers show a large western preponderance as will be seen from the following table :—

1919 July to December.	East.	West.	Percentage east.
Total number observed	596	706	45·77
Total areas in square minutes	221·9	244·0	47·63

The eastern prominences were on the average slightly brighter than the western.

Metallic Prominences.

The following metallic prominences were observed in the half-year :—

TABLE II.—LIST OF METALLIC PROMINENCES OBSERVED AT KODAIKANAL, JULY TO DECEMBER 1919.

Date.		Hour I.S.T.	Base.	Latitude. North.	Latitude. South.	Limb.	Height.	Lines.
1919.		H. M.	°	°	°		″	
July	4	8 29			4	W	75	b_1, b_2, b_3, b_4, 5316·8, D_1, D_2, 6677.
	8	9 20			9	W	25	b_1, b_2, b_3, b_4, 5316·8, D_1, D_2 6677, 7065.
August	4	8 37	1		6·5	E	30	b_1, b_2, b_3, b_4, 5316·8, D_1, D_2, 6677.
	13	8 55	6	6		E	90	b_1, b_2, b_3, b_4, 5316·8, D_1, D_2, 6677.
September	12	10 15			15	E	50	b_1, b_2, b_3, b_4, 5316·8, D_1, D_2.
	12	10 3			3	W	25	b_1, b_2, b_3, b_4, 5316·8, D_1, D_2.
	22	8 39	12		15	E	45	4924·1, b_1, b_2, b_3, b_4, 5316·8, 5535·1, D_1, D_2, 6677, 7065.
October	5	8 31	8		11	W	40	b_1, b_2, b_3, b_4, 5316·8, D_1, D_2, 6677.
	6	9 2			14	W	160	5016, 5018·6, b_1, b_2, b_3, b_4, 5316·8, D_1, D_2, 6677, 7065.
	7	9 30		14		E	110	4924·1, b_1, b_2, b_3, b_4, 5316·8, D_1, D_2, 6677, 7065.
	8	9 0			13	W	10	b_1, b_2, b_3, b_4, 5316·8, D_1, D_2, 6677, 7065.
	10	8 42	2		30	E	35	b_1, b_2, b_3, b_4, 5316·8, D_1, D_2.
	10	8 26	2		15	W	20	b_1, b_2, b_3, b_4, D_1, D_2.
	12	9 20	3	31·5		W	30	b_1, b_2, b_3, b_4, 5316·8, D_1, D_2.
	21	8 45	7	16·5		W	15	b_1, b_2, b_3, b_4, 5316·8, D_1, D_2.
	27	8 45		10		W	15	5016, b_1, b_2, b_3, b_4, 5316·8, D_1, D_2, 6677, 7065.
November	7	10 0			20	W	35	4924·1, 5016, b_1, b_2, b_3, b_4, 5316·8, D_1, D_2, 6677, 7065.
	15	8 19	14		25	E	75	b_1, b_2, b_3, b_4, D_1, D_2 bright over whole height.
	17	8 38	10		22	E	75	b_1, b_2, b_3, b_4, D_1, D_2.
	18	8 32	4		22	E	130	b_1, b_2, b_3, b_4, 5316·8, D_1, D_2.
	19	8 50			26	E	60	b_1, b_2, b_3, b_4, 5316·8, D_1, D_2.
	20	8 55	5		47·5	E	15	b_1, b_2, b_3, b_4, 5316·8, D_1, D_2.
	21	9 48	1		5·5	W	40	4924·1, b_1, b_2, b_3, b_4, 5316·8, D_1, D_2.
	22	8 20	2	19		E	100	4924·1, 5016, b_1, b_2, b_3, b_4, 5316·8, D_1, D_2, 6677, 7065.
December	10	9 10			16	E	50	b_1, b_2, b_3, D_1, D_2.
	11	9 8			23	E	45	b_1, b_2, b_3, b_4, 5316·8, D_1, D_2.
	11	8 50	3		19	W	25	b_1, b_2, b_3, b_4, 5316·8, D_1, D_2.
	13	8 43	10		8	E	40	b_1, b_2, b_3, b_4, D_1, D_2.
	13	8 42	1		23·5	E	35	b_1, b_2, b_3, b_4, D_1, D_2.
	13	8 53		23		W	15	b_1, b_2, b_3, b_4, 5316·8, D_1, D_2 bright over whole height.
	14	8 48			15	E	40	b_1, b_2, b_3, b_4, D_1, D_2.
	21	8 56	12	15		W	60	b_1, b_2, b_3, D_1, D_2.

The metallic prominences recorded above were distributed in latitude as follows :—

	Numbers.	Mean latitude.	Extreme latitudes.
North	8	16°·9	6° and 31°·5
South	24	17°·0	3° and 47°·5
Total ...	32		

17 were observed on the east limb and 15 on the west.

I–A

Displacements of the hydrogen lines.

Particulars of the displacements observed in the chromosphere and prominences are given in the following table :—

TABLE III.

Date.		Time I.S.T.		Latitude.		Limb.	Displacement.			Remarks.
				North.	South.		Red.	Violet.	Both ways.	
1919.		H.	M.	°	°		A	A	A	
July	3	8	42		46	W		2		No prominence.
	3	8	40		7	W		Slight		In two or three places.
	3	8	38	28·5		W	Slight	1		At top in different places.
	4	8	29		6	W			Slight	
	6	11	5		14	W	1			
	8	9	8	71·5		E	2			
	8	9	45		7·5	E		1		
	8	9	14	55		W	Slight			
	12	9	2		77·5	E		Slight		
	15	9	25	85		W		0·5		
	16	9	46		10	E	3			
	16	9	26	39		W		Slight		
	16	9	23	68·5		W	Slight			
	16	9	20	72·5		W		Slight		No prominence.
	19	9	15		2·5	W	2			
	20	8	55		9	W	1·5			
	21	9	27		6	W	3	2		To red at top ; to violet at base.
	23	8	50	18		W		Slight		
	24	10	50		8·5	W	1			
August	4	8	37		6·5	E		0·5		
	4	8	35		16·5	E			Slight	
	7	9	40		14	E	1·5			
	7	9	20		18	W			Slight	
	11	9	30	5		E	Slight			
	11	9	35		13·5	E			Slight	
	11	9	14	32·5		W	Slight			
	12	9	25	10		E		2		
	13	8	55	6		E		Slight		
	13	8	41	38·5		W		Do.		At base.
	14	9	50	9·5		E	2	Do.		To red at base ; to violet at top.
	15	8	45		13	E		1		At top.
	15	8	32	60·5		W		0·5		
	16	9	5		4·5	W	Slight			
	17	9	58		4	W		Slight		
	21	8	50		16·5	E		Do.		
	23	9	0	15		W	1·5			
	23	8	56	25·5		W	1			
	24	11	25		5	W	2	4		To red at south end and violet at north end.
	27	8	54	83		E	Slight			
	27	9	6		15	W		1		
	29	8	36	28		W	Slight			
September	4	8	36	82·5		E	Do.			
	4	8	42	71·5		W		1		No prominence.
	8	8	26	71·5		E	1			
	9	8	51	19		E	Slight			
	9	8	42		14	E	Do.			
	10	8	45	2		W		2		
	10	8	48	14·5		W		1		
	10	8	35	66		W	Slight			
	11	9	40		8	W	1			
	11	9	38		2	W		Slight		
	11	8	56	60		W		Do.		
	12	10	16		4·5	E	0·5			
	12	10	3		8·5	W	0·5			
	14	9	12	22		E	1			
	14	8	52	72·5		W		Slight		

Date.		Hour I.S.T.		Latitude.		Limb.	Displacement.			Remarks.
				North.	South.		Red.	Violet.	Both ways.	
1919.		H.	M.	°	°		A	A	A	
September	15	8	51	16·5		E	Slight			
	15	8	44		11	W	Do.			
	19	9	38	12		E	1			At top
	19	9	30		13	W		1		
	21	8	40	2		W		0·5		At south end.
October	2	8	56	35·5		W		1		
	2	8	52	82·5		W		Slight		
	4	11	50		69	E		Do.		
	5	8	26	21		W		Do.		
	6	11	10		14	W	5	6		To red at top; to violet at base.
	6	8	55	14		W	2·5			
	6	8	45	42·5		W	Slight			
	6	8	31	59·5		W		Slight		
	7	9	30	14		E		1		At base.
	7	9	36		10	E	0·5	Slight		To red at top; to violet at base.
	7	9	8		18·5	W		Do.		At base.
	7	9	0	35		W		Do.		Do.
	8	9	22		76·5	W		Do.		
	8	9	16		13·5	W	4			
	8	9	16		7·5	W	2·5	2		To red at top over 3° and to violet at base.
	9	8	50	20·5		W	Slight			
	10	8	35	30·5		E		Slight		
	10	8	37	6		E		Do.		
	11	8	28		61·5	E	Slight			
	12	9	20	31·5		W	1			
	13	8	34	45·5		W	2			At top.
	15	9	15		44·5	E		Slight		
	15	8	52	75·5		W	Slight			
	21	8	45	16·5		W	2	1·5		To red at top; to violet at base.
	24	8	59		22	E	Slight			
	26	8	50	82		W	1			
	27	8	31	39		E		3		
	27	8	23		12·5	E	Slight			
	27	8	45	10		W		2		
November	7	10	0		20	W	0·5			
	7	9	58	9		W		0·5		
	9	9	4	24		W		1		At base.
	11	8	30	65		W		Slight		
	11	8	28	72·5		W		Do.		At base.
	15	8	11		86·5	W	Slight			
	15	8	28		7	W	Do.			At top.
	17	8	32		73·5	E	1·5			
	20	8	35		65	W	Slight			
	21	9	48		5·5	W	2			
	22	8	14		85·5	W		1·5		
	25	8	40	80		E	1·5			
	26	8	35		3	W	0·5			
	26	8	34	1		W	0·5			
	27	8	54	39		E		1		
	27	8	43	17		W		Slight		
December	1	10	35		17	W		Do.		
	4	9	2	15		W	1·5			At base.
	4	8	52	81		W		Slight		
	7	8	35	70		W	3			At top.
	9	9	3	8		E		0·5		Do.
	10	8	48		16	W		Slight		At base;
	10	8	48		11	W	Slight			
	11	8	30	42		W		Slight		At base.
	12	8	31		73·5	W		1		No prominence.
	17	11	18	69		W		Slight		At base.
	17	9	3	16		E	1			
	21	8	56	13		W		1		At base.
	22	8	39		82	W		Slight		

Date.	Hour. I.S.T.	Latitude. North.	Latitude. South.	Limb.	Displacement. Red.	Displacement. Violet.	Displacement. Both ways.	Remarks.
1919.	H. M.	°	°		A	A	A	
December 22	8 36	Equator.		W			Slight	
25	8 42		6	E		2		
25	8 44		17	E	2			
25	8 36		15	W		Slight		At top.
27	8 32		18	E	0·5			At base.
27	8 29		42	E	Slight			

The total number of displacements was 125 of which one was on the equator and the rest were distributed as follows :—

Latitude.	North.	South.
1° to 30°	31	45
31° to 60°	15	4
61° to 90°	20	9
Total ...	66	58
East limb	42	
West limb	83	
Total ...	125	

63 displacements were towards the red and 65 towards violet. These include eight occasions in which the displacements were to red and to violet in different parts of the same prominence. 5 displacements were both ways simultaneously.

The large decrease in the number of displacements observed at the limb, as also in the number of metallic prominences, is in part due to the unsatisfactory observing conditions during the period under review.

Reversals and displacements on the disc.

111 bright reversals of the Hα line, 14 dark reversals of the D_3 line and 84 displacements of the Hα line were recorded during the half-year. All these are in defect compared with the previous half-year. Their distribution is shown below :—

	North.	South.	East.	West.
Bright reversals of Hα	39	72	53	58
Dark reversals of D_3	6	8	7	7
Displacements of Hα	29	55	42	42

65 of the displacements were towards red, 16 towards violet and three both ways simultaneously.

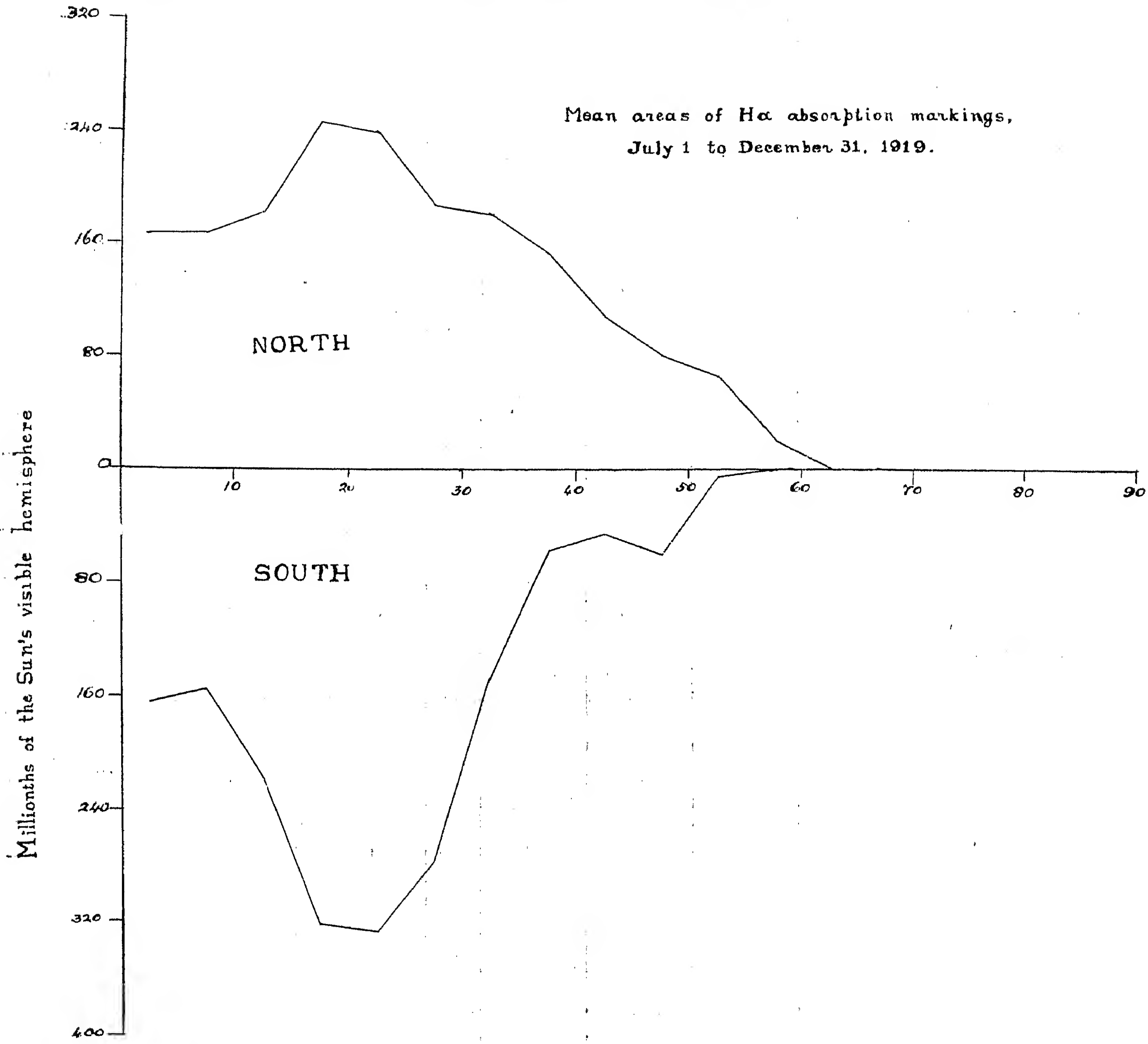
Prominences projected on the disc as absorption markings.

Photographs of the sun's disc in Hα light were obtained on 116 days counted as 109 effective days. The mean daily areas in millionths of the sun's visible hemisphere, corrected for foreshortening, and the mean daily numbers are given below :—

	Areas.	Numbers.
North	1798	9·9
South	1791	9·5
Total ...	3589	19·4

As in the case of prominences at the limb, the mean areas show an increase and numbers a decrease in both hemispheres.

The distribution in latitude is represented in the accompanying diagram.



The absorption markings representing the denser prominences are distributed between the equator and latitude 60° north and south as in the case of prominences at the limb but with much more pronounced maxima at about latitude 20° north and south than is shown in the prominence diagram. The distribution is almost the same as in the previous half-year but the southern maximum has moved nearly 10° towards the equator and the region of slight activity previously shown between 50° and 60° south has also decreased ten degrees in latitude.

Unlike prominences at the limb, both areas and numbers show an eastern excess, the percentage east being 51·98 for areas and 51·56 for numbers.

KODAIKANAL OBSERVATORY,
16*th March* 1920.

J. EVERSHED,
Director, Kodaikanal and Madras Observatories.

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Kodaikanal Observatory.

BULLETIN No. LXIII.

SOME FEATURES OF Hα DARK MARKINGS ON THE SUN, BY T. ROYDS, D.Sc.

The dark markings seen in spectroheliograms of the sun taken with the Hα line form one of the most interesting features of the solar surface and one that has been least studied. Since the Hα spectroheliograph of the Kodaikanal Observatory was first constructed by Mr. Evershed he has carried out many minor improvements which enable a higher average quality of photographs to be obtained, resulting in a more perfect and more continuous series of Hα spectroheliograms than in the earlier days. Experience has also been gained in the preparation of red sensitive plates. It therefore seemed appropriate to undertake a detailed study of the Hα records now available at the Kodaikanal Observatory, and a commencement has been made on the photographs taken during the half-year January—June 1918. A still earlier period might have been taken, but it was thought advisable to begin with a period when there was considerable prominence activity in the polar regions (see Kodaikanal Observatory Bulletin No. LIX).

Even a casual inspection of Hα spectroheliograms reveals certain features which can hardly escape notice, and the present paper confines itself to these more obvious features of the markings as exemplified in the spectroheliograms obtained during the half-year January--June 1918, leaving for another occasion those features requiring a more closely detailed examination. The remarks in this paper are therefore concerned only with the following three points which have not, so far as I am aware, been previously referred to by other workers :—

I. The mean directions of Hα dark markings in different latitudes.*
II. The bright margins of Hα dark markings.
III. Absorption near the bases of prominences.

I.—The mean direction of dark markings in different latitudes.

Almost every spectroheliogram shows that nearly all dark markings have a more or less linear character, this feature having led M. Deslandres to call them " filaments ".† Consequently it is not difficult to assign a definite direction to each marking or at any rate to different sections of its length. The tendency of Hα markings to lie along a parallel of latitude in latitudes higher than about 35° and to lie along a meridian in the equatorial regions can be gathered after a slight familiarity with the spectroheliograms. For a closer study, the average direction of the dark markings for each belt of 5° of latitude for the northern and southern hemispheres has been derived in the following way. In the course of the ordinary routine of the Observatory the dark markings are copied by hand on to 8 inch charts on which are printed the lines of latitude and longitude referred to the central meridian at 5° intervals. From each of these charts of the first half of 1918 the direction of the Hα markings in each belt of 5° latitude was read off, the areas having been previously measured on the photographs and corrected for foreshortening. For consistency, the direction was reckoned from that end of the marking which was nearer the equator ; thus one lying along a meridian was called N if in the northern

* The direction of Hα markings is treated of in Kodaikanal Observatory Memoirs, Vol. I, part II, page 119.

† Annales de l'Observatoire d'Astronomie physique, Meudon, Tome IV.

hemisphere and S if in the southern. In the northern hemisphere, the markings were classified as E, ENE, NE, NNE, N, NNW, NW, WNW or W by estimation from the charts; in the southern hemisphere similarly from E to W by S. The only point of difficulty is whether a marking which lies exactly along a parallel of latitude shall be called E or W. In this discussion such a marking has been called E as if its eastern end had been slightly nearer the pole than its western end; this may not be strictly accurate but it is more accurate than dividing them equally between E and W, for it will be seen that there is a large preponderance of markings which incline themselves towards the east over those inclining towards the west. For example in the northern hemisphere the total area of markings during the half-year which were classified as ENE, NE, and NNE was 1,447 tenths of a square minute, whilst that of markings WNW, NW, NNW was 410 only; similarly in the southern hemisphere those ESE, SE, and SSE totalled 1024 tenths of a square minute whilst those WSW, SW, and SSW were only 420. Markings whose direction was indeterminate owing to their appearing as dots or as irregular patches were omitted, as also a number of markings of insignificant size as well as those in the highest latitudes where markings are so infrequent that their average directions during a period of only six months cannot be relied on. The area of markings omitted on all accounts was, however, only 15 per cent of the total.

Briefly, what has been done is, in effect, to place the Hα markings in each belt of 5° end to end so as to form one long irregular marking and to draw a line from the beginning of this long marking to the end: this only differs from what was actually done in that the areas of the markings were taken and not their lengths.

The average direction of the Hα markings in each belt is shown in figure 1 and in table I, the lengths of the lines in the figure being proportional to the vector sum of the areas. The total areas in each belt quite independent of their direction is given also in table I and it will be seen by comparing this total with the vector sum that the markings deviating from the average direction do not form a large proportion.

INCLINATION & AREAS of Hα MARKINGS FOR EACH BELT of 5° (JANUARY-JUNE, 1918)

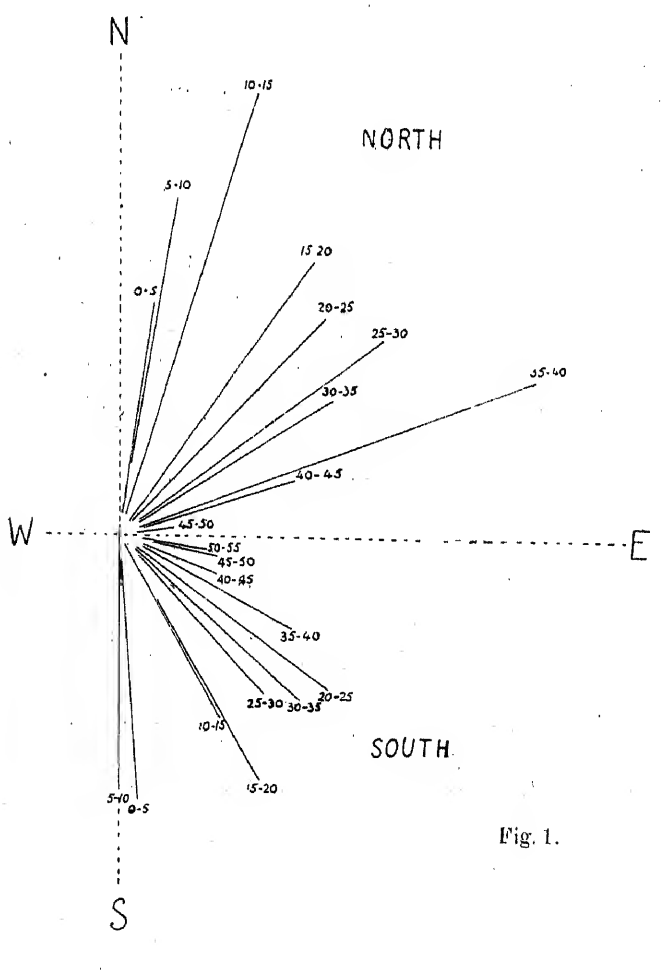

Fig. 1.

TABLE I.—Mean direction of dark markings in different latitudes.

North Latitudes	0°–5°	5°–10°	10°–15°	15°–20°	20°–25°	25°–30°	30°–35°	35°–40°	40°–45°	45°–50°	50°–55°	55°–60°	
Total areas in $\frac{\square'}{10}$	319	478	634	513	400	444	378	577	225	63	30	11	
Vector sum	257	373	505	365	327	356	275	482	200	60	27	9	
Mean direction (north of east)	82°	81°	73°	55°	47°	37°	33°	21°	18°	8°	15°	0°	
South latitudes	0°–5°	5°–10°	10°–15°	15°–20°	20°–25°	25°–30°	30°–35°	35°–40°	40°–45°	45°–50°	50°–55°	55°–60°	60°–65°
Total areas in $\frac{\square'}{10}$	388	384	323	441	356	266	324	268	152	132	130	48	10
Vector sum	290	279	228	307	281	233	267	212	114	110	95	44	10
Mean direction (south of east)	86°	90°	61°	60°	36°	47°	42°	28°	21°	12°	9°	1°	0°

The chief features of the results shown in figure 1 are (i) that in both hemispheres the markings incline themselves to the east and (ii) that as one passes from the equator the average direction of markings changes from a position along a meridian by inclining more and more towards the east until in the higher latitudes they lie practically along a parallel of latitude. These features of Hα markings seeming to prefer one direction varying with latitude over another, and that always to the east can be accounted for by the polar retardation of the angular velocity of rotation of the sun ; but this by itself is not sufficient for it requires that the age of the marking in different latitudes is equal to that required to produce the easterly drift of its polar end which is indicated in figure 1. If Hα markings are of short duration they will have disappeared before the end nearer the poles have acquired any appreciable easterly drift ; if, however, they are of considerable duration it is easy to see that as the age of the marking increases the end which is in a higher latitude and consequently rotating more slowly, will gradually drift towards the east relative to the end in the lower latitude. It should however be stipulated that the age of the marking in this sense does not necessarily mean the length of time the marking is visible, for if the origin of an Hα marking is operating invisibly for a considerable time before the Hα marking becomes visible at the surface the eastern tendency of Hα markings would still be produced.

Let us examine what must be the "age" of Hα markings (in the above sense) in different latitudes to produce the inclinations observed in figure 1. These are given in table II. The polar retardation operating has been supposed to that given by Adams for the reversing layer[1] ; the ages deduced vary from about 8 days in the belt 0°—10° to about 116 days in the belt 45°—65°. If the polar retardation had been taken from Adams' values for the Hα line, the ages deduced would have ranged from 22 to 290 days.

TABLE II.

Latitude	0°—10°	10°—20°	20°—35°	35°—45°	45°—65°
Mean directions N and S	84°·5	63°·5	40°	22°	9°
Easterly longitudinal drift per diem ...	0°·11	0°·30	0°·74	0°·60	1°·12
"Age" of Hα markings in days ...	7·9 days	16·6	24·1	41·0	116

[1] Adams, Papers of the Mt. Wilson Observatory, Vol. I, Part I.

The question now arises as to whether the "ages" shown in table II correspond with any exactitude with the duration of Hα markings as observed in the daily spectroheliograms. It is not, however, easy to determine exactly the average duration of Hα markings for several reasons, chief among which are (1) the fact that there are sometimes gaps of several days in the Hα record owing to bad weather, (2) the fact that it is often difficult to decide whether a marking which has reappeared at the eastern limb is identical with one which disappeared at the western limb or a new birth in approximately the same position, for seldom does a marking reappear with characteristics which can be definitely correlated with its features when it disappeared at the western limb and (3) the fact that many markings are born on the invisible side of the sun before they appear at the eastern limb, and many die there also after disappearing at the western limb. The spectroheliograms for the half-year have however been examined in order to ascertain whether the duration of Hα markings is consistent with the "age" deduced in table II. In the northern hemisphere an average duration of 25 days was found and in the southern, 10 days. These values are not so consistent with each other as, possibly, they might have been if a longer period had been taken, but at any rate it suffices for the present to have found no appearance of any tendency for markings in high latitudes to last longer than those in low latitudes. Consequently if polar retardation of the sun's rotation is the sole cause of the easterly tendency of Hα markings, the logical conclusion seems to be that in high latitudes the disturbance which finally appears as a dark marking is operating long before the marking becomes visible.

II.—Bright Margins of Hα Markings.

When an Hα dark marking is near the limb the side of the marking which is nearer the centre is almost invariably bounded by a bright marking, extending for practically the whole length of that side of the dark marking. Generally there is no bright marking visible on the side nearest the limb. A good example is shown in figure 2 which is an enlargement of a portion of a spectroheliogram taken on February 6, at $8^{h}\ 10^{m}$ I.S.T. A pothook-shaped marking is near the east limb and the side nearest to the centre of the sun's disc is seen to have a wellmarked bright margin. When a dark marking is at the east limb the western side has the bright margin, when at the west limb the eastern side shows the bright margin. These bright margins are very noticeable only when the marking is near the limb but they can generally be seen in markings all over the disc though they are much less marked and are not always there seen along the whole length of the dark marking. The ready visibility of the bright margin when the marking is near the limb is probably due to scattering in the lower layers. At a certain distance from the limb varying for different markings it can be seen that although the contrast around the bright margin is becoming less, a bright margin begins to appear also on the limb side of the dark marking. The same marking shown on figure 2 is seen again on February 12th in figure 3 when the vertical portion is near the centre of the sun's disc. Although possibly not showing in the reproduction there is now clearly visible in the original a bright margin on each side of the dark marking extending for most of the length of the dark marking but it will be seen with how much less contrast compared with figure 2. The width of the bright margins in these photographs is about equal to that of the dark marking and they are not appreciably wider than here shown even with much broader dark markings.

Since the bright margins are seen on opposite sides of the dark marking at the two limbs, and on both sides, though with reduced contrast, when near the centre of the disc, it is concluded that they are in existence on both sides all the time but that when near the limb the bright margin on the limb side is obscured by the dark marking which reaches to a higher level. Two facts go to confirm this interpretation, viz., (1) if a dark marking near the limb happens to be directed approximately radially to the centre of the disc the two sides are seen to have bright margins; and (2) if a marking near the limb is sinuous in shape, the bright margin is seen to seek the side nearest the centre.

The height of the dark marking above its bright margins can be deduced from the distance of the marking from the centre of the disc when the bright margin on the limb side begins to be uncovered by the dark marking (when east of the central meridian) or covered (when west). For any particular marking the distance at which the bright margin on the limb side begins (or ceases) to appear cannot always be exactly determined because, firstly, as the marking approaches the centre although it may not be difficult to say when the bright margin on the limb side has become visible, the contrast is considerably reduced so that to say when the bright

margin *begins* (or *ceases*) to appear is not so easy; and secondly, even at the best, the successive spectroheliograms represent intervals of one day. A large number of markings seen during the half-year have however been examined, particularly those which lie approximately at right angles to the solar radius, and although there is considerable variation among them the bright margin on the limb side was never obscured when within about 30° of the centre of the sun's disc. The average width of the bright margins measured was about 0·22 mm, the sun's diameter being 60 mm. Taking this as being completely obscured when beyond 30° from the centre, it follows that the height to which a dark marking towers over its bright margins is equal to $0{\cdot}22 \times \sqrt{2} = {\cdot}311$ mm which is equivalent to 10″ of arc.

Having now obtained a measure of the relative heights of the dark markings and their bright margins it is important to fix their level in the sun, but there is very little evidence to settle this point. From what follows in section III of this paper it will however be seen that absorption is frequently seen at the bases only of prominences at the limb, i.e., just above the chromosphere, from which we conclude that the bright margins of the $H\alpha$ marking do not reach higher than the chromosphere, for if they did they would mask this absorption. Hence although the evidence is very meagre we will take it for the present that the bright margins of $H\alpha$ markings are situated in the chromosphere and consequently that the dark markings do not generally reach higher than 10″ above the chromosphere.

It is hardly probable that the bright $H\alpha$ structure exists only at the margins of the $H\alpha$ dark marking but rather that it extends also right across, but underneath, the whole width of the dark marking forming a base on which the dark marking forms a narrower superstructure.

Perhaps a word should be said as to the relative frequency of occurrence of dark markings unaccompanied by bright margins on either side. A good deal depends of course on the quality of the photographs, for good definition, accurate focussing and good contrast in the plate are all requisite for there to be much chance of seeing the bright margins especially if the marking is not near the limb. It is estimated, however, that only in about 15 per cent of the total dark markings observed are bright margins absent when the quality of the photographs would lead one to expect them to be visible.

III—Absorption at the Bases of Prominences.

The brightest of the prominences at the limb of the sun can generally be seen in $H\alpha$ spectroheliograms of the solar disc, provided the sky is clear and the plate is not underexposed. In a number of prominences seen thus, there can be seen a dark strip, suggesting absorption, near the base of the prominence, giving the appearance that the prominence, or part of it, is cut off from the disc at its base. Such cases are illustrated in figure 4, February 1, 1918, $8^h\ 13^m$; figure 5, February 1, 1918, $9^h\ 26^m$; figure 6, March 4, 1918, $8^h\ 11^m$. Considering the difficulties which may be expected in photographing a phenomenon of this kind, prominences showing this characteristic are of surprisingly frequent occurrence; exactly how frequent is chiefly a matter of the quality of the photographs but an idea may be gained from the fact that of 103 prominences seen on $H\alpha$ plates during the three months January to March 1918, absorption was visible at the bases of 37, of which 14 were doubtful.

Certain features of the phenomenon illustrated in the above figures must be closely examined before proceeding further. Firstly, as to whether the absorption is taking place just inside the limb or is actually absorption of the prominence outside the limb. An examination of the photographs reproduced will suffice to settle the point. In figure 4, February 1, 1918, $8^h\ 13^m$ there is no doubt that the absorption near the middle of the prominence is not on the disc but on the prominence; in this case there extends from this middle region to the southern end of the prominence a much narrower absorption line (possibly not visible in the reproduction) which also is on the prominence. In figure 5, February 1, 1918, $9^h\ 26^m$, the absorption begins on the prominence at the southern end but as it runs towards the northern end comes on to the disc. Such cases of absorption clearly on the prominence and off the disc could easily be multiplied. The differences between the two photographs on February 1 would appear to be rather changes in the prominence than due to a changed aspect on account of the rotation of the sun in the interval between them. In figure 6, March 4, 1918, the absorption is partly on the disc and partly on the prominence. There is, of course, no difficulty in finding cases in which the absorption is completely inside the limb where a prominence may be seen, and is really an absorption of light from the disc just as in any $H\alpha$ dark marking seen near the centre of the disc.

Secondly there can be no reasonable doubt that the dark strip at the base of such prominences as illustrated are produced by absorption for they frequently are continuous with absorption on the disc. It is conceivable that a prominence floating just above the chromosphere would have the same appearance as many of these cases but the occurrence is too frequent and too much alike in its general features to be due to floating prominences in every case; moreover the prominence photographs in calcium light show that the prominences under discussion are not floating. The question of the possibility of their being spurious, due, say, to the tremor of the sun's disc has been considered but no adequate reason for the unreality of the phenomenon can be conjectured.

The general features of the absorption at the bases of prominences are very similar in the different cases. There is a dark narrow strip extending along the base of the prominence and is seen never higher than just outside the sun's limb although it may be seen either partly on the disc and partly on the prominence or on the disc just inside the limb as may be expected if the base of the prominence is not exactly at the limb at the time of the photograph. It is therefore concluded that when the phenomenon is exactly at the limb the absorption is taking place just above the chromosphere. The average width of the absorption strip may be taken as about ·20 mm with a 60 mm diameter of the sun, which corresponds to 6″·4 of arc, representing the height above the chromosphere to which the absorption extends.

The absorption typified in figures 4, 5 and 6 may not be of a different character from that discussed by Buss[1] who however speaks rather of absorption reaching to any level above the limb, but I would regard the latter cases as peculiar to the particular prominence whereas the absorption at the bases is typical of all prominences seen under favourable conditions.

The exact relation of an $H\alpha$ dark marking with the prominence almost invariably visible when the marking reaches the limb has been an interesting question ever since the markings were first photographed. The first assumption naturally was that the dark marking on the disc and the prominence at the limb were merely different aspects of the same thing, but as it was found that prominences or parts of them do not always show as $H\alpha$ markings, and vice versa, this could not be wholly true. The hypothesis that dark markings represent the cooler parts of the prominences also will not fit the facts. It has therefore been supposed, by Mr. Evershed and possibly by others also, that not all parts of prominences contain sufficient hydrogen to effect appreciable absorption of the photospheric light, and that only the denser parts of prominences will show as absorption markings.

We will now see what additional information on this question is afforded by the phenomena described in the above sections II and III. In the light of this information a typical prominence is imagined to be constituted as follows. A prominence has its base in a region of high temperature probably at the chromospheric level emitting light more strongly than the surrounding chromosphere. The prominence is cooler than this base and indeed cooler than the general chromosphere. When the prominence is near the centre of the disc it absorbs $H\alpha$ light emerging from the chromosphere, but only in those portions where there is sufficient amount of hydrogen to effect appreciable absorption; these portions will consequently appear as a dark marking with bright margins on each side due to the emission from the base. When the prominence is seen in profile at the limb, absorption is taking place under somewhat different conditions owing to the changed aspect; instead of the denser portions of the prominence absorbing light from the chromosphere we now have the outer and cooler portions of the prominence absorbing the light from the inner and hotter region but only near the base does the light traverse sufficient thickness to suffer appreciable absorption.

I am greatly indebted to Mr. Evershed, F.R.S., for his criticism and suggestions and also to the various members of the staff who were on spectroheliograph duty during the half-year under consideration.

SUMMARY.

The average direction of $H\alpha$ dark markings changes from a direction along a meridian in equatorial regions by steadily inclining more and more towards the east until in latitudes higher than about 35°, the markings lie nearly along a parallel of latitude. These features can be explained by the polar retardation of

[1] Buss, Observatory, 36, 225, 1913.

Fig. 2. H α dark marking on Feb. 6, 1918. Showing bright margin on side farther from the limb.

Fig. 3. The same marking near the central meridian on Feb. 12, 1918. Bright margins are visible in places on both sides but with much less contrast.

Fig. 4. Feb. 1, 1918. $8^{h.}\ 13^{m.}$

Fig. 5. Feb. 1, 1918. $9^{h.}\ 26^{m.}$

Fig. 6. Mar. 4, 1918.

Figs. 4—6 are examples of H α prominences at the limb showing absorption near their bases.

Photo-engraved & printed at the Offices of the Survey of India Calcutta 1920.

the rotation of the sun, but this requires that the age of the dark markings should vary from about 8 days near the equator to about 116 days in latitude 55°. The observed duration of Hα markings is consistent with the above value for equatorial regions but there seems no evidence of longer duration in higher latitudes.

2. Dark markings near the limb are seen to have almost invariably a bright margin on the side nearest the centre. Since a bright margin appears on opposite sides of the dark marking at the two limbs, and on both sides, though with reduced contrast, when near the centre of the disc, it is concluded that they are in existence on both sides all the time but that when near the limb, the bright margin on the limb side is obscured by the dark marking which reaches to a higher level. From the distance from the centre of the disc at which the bright margin on the limb side becomes visible and its width when near the centre of the disc it is deduced that the dark marking reaches to a height rarely more than 10″ above the level of the bright margin, and that parts of a prominence above a height of about 10″ do not contain sufficient hydrogen to exercise appreciable absorption of the light from the disc.

3. A narrow absorption strip at the base of prominences in profile at the limb is seen in more than 25 per cent of the total number of prominences photographed in Hα light and would appear to be typical of the majority of prominences when their base is exactly at the limb. This absorption strip has a width of about 6″ and it is concluded that only up to this height is there sufficient hydrogen in the outer and cooler portions to effect absorption of light from the inner portions of the prominence.

KODAIKANAL OBSERVATORY,
5th August 1920.

T. ROYDS,
Acting Director.

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Kodaikanal Observatory.

BULLETIN No. LXIV.

ON THE DISPLACEMENTS OF THE TRIPLET BANDS NEAR λ3883 IN THE SOLAR SPECTRUM.

BY J. EVERSHED, F.R.S.

In Kodaikanal Observatory Bulletin No. 39 some measures are given of the displacements at the centre of the Sun's disc of eight of the triplet bands between 3876 and 3882. The mean value of these and of three separate lines attributed by Rowland to carbon was + 0·0045 A, according to measures by the writer. If to this is added the value, + 0·002 A, found by Adams for the shift limb − centre for these bands the total shift limb — arc amounts to + 0·0065 A, a value approximating to the shift predicted by Einstein which for this region of the spectrum is + 0·0082 A.

More recent measures of these bands by St. John* indicated very much smaller shifts, the mean being +0·0018 A, at the centre of the disc, or less than one half the value obtained at Kodaikanal. St. John also measured 43 single lines of the carbon arc spectrum in the same region including 18 lines of intensities ranging from 2 to 4 and 25 lines of intensities between 00 and 1 of Rowland's Preliminary Table. These gave large individual differences, the shifts of the stronger lines, Sun − arc, ranging from + 0·006 A to − 0·003 A, and the weaker lines from + 0·004 A to − 0·003 A. The mean value for the stronger lines was + 0·0024 A, and for the weaker lines + 0·0006 A. At the Sun's limb his measures of 18 of the same series of stronger lines gave a mean value + 0·0037 A, whilst his means for 17 lines of the fainter series was zero.

With a view to clearing up this discrepancy between the Kodaikanal and Mount Wilson measures a new series of photographs was secured at Kodaikanal in March and April 1918. These were obtained with the large spectrograph described in Kodaikanal Observatory Bulletin No. 36, using the Anderson 6-inch grating with a ruling of 75,000 lines. Fourth order spectra were photographed at the centre of the disc, but most of the limb spectra were taken in the third order. The linear dispersion is 0·48 A per millimeter in the fourth order and 0·79 A per millimeter in the third order. The definition in both orders is very fine, and there is no trace of astigmatism. The band 3880·53 is partially resolved in the arc spectra of the fourth order, the triplets on the more refrangible side of this being clearly resolved.

Great care was taken to obtain plates only in the clearest possible sky when no trace of scattered white light was visible near the Sun; in all cases also the altitude of the Sun exceeded 60°. The wave lengths of lines which are shifted towards red at the limb are reduced by scattered light, which superposes light from the centre of the disc, and this is especially liable to occur in the ultra-violet region where the scattering is greater than in the visible region.

The usual reflecting device was used for simultaneous exposures on Sun and arc, care being taken to insure the complete illumination of the grating by light from both sources. The slit width was between 0·010 mm. and 0·015 mm. with a collimator lens of 7′ 6″ focus.

In photographing the polar limb spectra the time was computed beforehand and for each day when the vertical diameter of the Sun's image projected by the siderostat coincided with the solar axis. This is easily

* Astrophysical Journal 46, 263.

done and without any chance of mistakes by means of the tables constructed for the spectroheliograph work. Photographs were then made of the North and South polar limbs alternately as near to the computed time as practicable. For the fourth order plates exposures of 2 minutes on Sun and 3 minutes on arc were found sufficient at the centre of the disc, and for the limb spectra in the third order the exposures were about 5 minutes on the Sun and 1 minute on the arc.

The Sun's image enlarged to a diameter of 80 millimeters was projected on to an engraved plate placed in front of the spectrograph slit. A hole in the plate 1 mm. in diameter and 1 mm. inside the limb admitted light to the slit. This hole was also the centre of a circle of 40 mm. radius upon which the image could be centred when photographing the centre of the disc.

The limb spectra represent points on the Sun 1/40 of the radius within the limb, the exact heliographic co-ordinates of which may be computed, using the middle time of exposure to determine the position angle of the slit on the Sun's disc. As they were mostly taken very near to the north or south polar limbs the corrections for the solar rotation are very small or zero, but in all cases where the point photographed was at an appreciable distance from the Sun's axis the component in the line of sight of the solar synodic rotation was computed by the formula $V = [1{\cdot}507 \cos\phi + 0{\cdot}546 \cos^3\phi - C] \sin\lambda \cos D$.* The velocity thus obtained was added algebraically to the velocities due to the Earth's orbital and diurnal movements and the resultant velocity expressed in angstroms applied to correct the measured displacements.

The Earth's orbital motion in the direction of the Sun is determined from the daily values of the radius vector given in the Nautical Almanac and the component of the diurnal motion from the formula Velocity in Km/sec $= 0{\cdot}464 \cos\phi \cos\delta \sin T$.

The proper selection of lines or bands which may be supposed to be unaffected by the presence of superposed lines of other substances is not very easy. After a careful comparison of the arc and solar lines I originally selected the thirty lines or bands given in the following list, taken from Rowland's table of solar lines.

λ	Origin.	Intensity.	λ	Origin.	Intensity.
3819·197	C	1 Nd ?			
3819·346	C	1	3876·556	C	0
·412	C	1	·622	C	0
3822·406	C	0	3877·587	C	0
·470	C	0	·646	C	0
3830·745	C	0	3879·331	C	0
·801	C	0	·394	C	0
3831·174	C—	3d	·458	C	0
3835·298	C	0	3879·716	C	1
·342	C	0	·796	C	0
3836·639	C	1	·851	C	0
·689	C	1	3880·105	C	1
3844·378	C	4d ?	·175	C	0
3845·149	C	1	·235	C	0
3846·777	C	1	3880·465	C	1
·814	C	1	·532	C	2
3851·427	C	2 Nd ?	·596	C	1
3852·541	C ?	2 Nd ?	3880·815	C	1
3858·822	C	2 N	·931	C	1
3862·627	C ?	2	3881·140	C	1
3863·533	C	3 N	·254	C	1
3864·438	C	3	3881·445	C	2
3865·282	C ?	3	·543	C	1
3868·873	C	1	3881·729	C	1
·941	C	0	·825	C	1
3869·179	C	0			
·305	C	1			
3872·312	C	0			

* Kodaikanal Observatory Bulletin No. 49.

In making up this list I was guided mainly by the agreement in relative intensity between the lines in the carbon arc and the corresponding lines in the Sun as judged by superposing the arc images on the absorption lines in the solar spectrum and observing the 'fit' of the lines and bands when the arc spectrum has been made a suitable density. Many of the lines measured by St. John were rejected because of the want of agreement in relative intensities or, in the case of the fainter lines measured by him because of the inherent difficulty of measurement especially in the limb spectra. The list includes all of those given in St. John's table 1 B, consisting of his stronger lines and partially resolved triplets, excepting the following :—

λ	Reason for exclusion
3846·13, 3853·62	Relatively too strong in Sun
3856·80 ...	Difficult to measure satisfactorily
3866·12 ...	Diffused towards violet in Sun

I also exclude the lines 3876·448 and 3877·481 giving a shift towards violet at the centre of the disc, because they are relatively too strong in the Sun.

My plates are somewhat underexposed towards the more refrangible end, and this is an added reason for confining attention to the less refrangible bands and stronger lines.

A preliminary set of measures of some of the plates was made by the late Mr. R. J. Pocock, whose mean results Sun — arc may be briefly summarised as follows :—

North limb plates	+ 0·004 A
South limb plates	+ 0·008 A
Centre of Disc	+ 0·004 A

In a detailed comparison of his measures with those of St. John we found that there was a general agreement in the case of St. John's direct measures of Sun — arc, and for the lines in his table 1 B, but larger values were found for the triplet bands near 3883 which were more nearly in agreement with the original Kodaikanal measures quoted at the beginning of this paper.

In the measures now to be recorded I have practically confined attention to the triplet bands in the first head, for which Pocock's results differed from St. John. This series gives fairly accordant values of the displacement at the Sun's limb, but as in all Sun — arc measures the mean result of all the lines or bands on plates taken on different dates show discordances largely in excess of the probable error of measurement. It is desirable therefore to reduce to a minimum the time spent on any one plate.

Two methods of measurement have been adopted. The limb spectra have all been measured by the ordinary method of bisection with a single thread made approximately parallel to the spectrum lines by tangent screw adjustment. The centre of disc plates, in which the triplet bands are partially resolved in the Sun, were measured by the negative on negative method, which can be used with great effect when suitable duplicate negatives have been secured. In this two similar negatives A and B are placed film to film in the positive on negative micrometer, but are not reversed end for end. They are displaced laterally, so that the arc lines of A are superposed on the solar lines of B, and *vice versa*. The movement required to produce alternate coincidences measures the double displacement of the solar lines with reference to the arc lines. This method is especially suitable for measuring the stronger unresolved, or partly resolved, bands, but not for faint single lines. As in the positive on negative method used for other Sun — arc spectra, and for solar rotation spectra, the negative on negative measures are found to give slightly smaller values of the displacements than the bisection method.* This I consider may be due to an unconscious systematic overestimate of a small displacement when measuring by the ordinary method. It is not known how the discordance may vary with the amount of the displacement, but the effect on a measured displacement of 0·015 mm. is about 16 per cent, and in the present series of measures where the correction for motion is subtractive the difference between ordinary and negative on negative measures in the residual shift amounts to about 20 per cent. If we consider the

* Kodaikanal Observatory Bulletin No. 32.

negative on negative method to be more trustworthy an approximate correction may be applied to the measures made by the ordinary method, corresponding to a reduction of the shift by about one-fifth of its amount.

Results for the centre of the Sun's disc.—I now give in table I on page 303 the results of the measures of twelve centre of disc plates measured in six pairs by the negative on negative method. The mean shift Sun — arc for each of the bands is given in the last column, and the mean shift for all the bands in each pair of plates at the foot of the columns. The general mean is very nearly + 0·004 A if the anomalous result for April 6 is omitted or + 0·003 A if it is included.

The means for the individual bands, excepting one, vary from + 0·002 A to + 0·005 A. The exception, 3879·79, giving a zero shift needs further study. In our previous measures and in those of St. John the less refrangible portion of this band has a shift of + 0·003 A, and the difference may be due to the fact that in the negative on negative measures the entire triplet is measured as one line, whereas in the bisection measures the more refrangible single line 3879·716 of Rowland was omitted. This line (Series A_1 of Uhler and Patterson) may give a negative shift, as appears to be the case also with the lines of the same series at 3877·481 and 3876·448. These two lines were omitted from the present measures because their intensities and their positions relative to the doublets of the A_2 series differ markedly in Sun and arc. This is clearly shown by comparing the intensities and wave-lengths in Rowland's "Preliminary Table" with the table of carbon arc wave-lengths of Uhler and Patterson *; the intensity of each is relatively too great in the Sun and they are displaced towards violet 0·011 A and 0·008 A respectively. It seems most probable that these lines are blended with lines of other elements, otherwise it has to be supposed that under solar conditions there is some special perturbation affecting the wave-lengths and intensities of these particular lines of the A_1 series, including possibly the line 3879·716, but not other lines in the same series.

The more refrangible component of the triplet at 3879·39 appears to be blended with another line on its red side but this can have little or no effect on the position of the band as a whole.

The mean shifts for all the bands show a fair accordance on the different dates excepting April 6 which yields a zero result. This is not due to imperfect centring of the Sun's image on the slit, for a maladjustment amounting to about 6 mm. towards the east side would be required to neutralise by the solar rotation the mean shift towards red of 0·0037 A given by the other plates. Our long series of measures of Sun — Fe arc often have shown similar anomalies, due probably to local ascending currents at the centre of the disc; and we have recently proved that the spectrum lines may be locally displaced by small amounts at the centre as well as in other parts of the disc.

Measures by the negative on negative method have also been made of nine lines in the more refrangible region. The mean results for eight plates, including the pair of April 6 giving low values is as follows :—

λ	Origin.	Intensity.	Sun — arc in $\frac{A}{10,000}$.	Series (Uhler and Patterson).
3831·174	C	3 d	+ 71	A_1
3836·639	C	1	+ 59	A_1 B_1 C_1
·689	C	1		
3844·378	C	4 d ?	+ 37	A_1
3845·149	C	1	+ 37	B_1
3846·777	C	1	− 03	A_1
·814	C	1		
3851·427	C	2 N d ?	+ 43	A_1
3852·541	C	2 N d ?	+ 21	A_1
3868·873	C	1	− 03	B_1 B_2
·941	C	0		
3869·179	C	0	+ 39	A_1
·305	C	1		

Mean + 0·0033

Mean excluding plates of April 6 + 0·0043.

* Astrophysical Journal 42, 439.

The close agreement here shown with the mean shift for the ten bands gives some confidence in the statement that for the stronger lines and bands in the carbon arc spectrum there is a shift towards red at the centre of the Sun's disc which is near to the value +0·004 A. This is a trifle smaller than the value previously found at Kodaikanal, but the earlier measures were made by the ordinary bisection method, which as already stated gives larger values.

Results for the Sun's limb.—In the limb spectra the eight triplet bands and two doublets at 3876·6 and 3877·6 are not resolved. Owing to the widening of all lines near the limb the components merge into one another and no spectrograph can resolve them.* I have found that the third order spectra with lower dispersion and greater contrast are more satisfactory to measure than the fourth order plates. The bands are of more uniform density than at the centre of the disc, and they can be easily measured as single lines by the bisection method. The negative on negative method would have been preferable, but suitable pairs of negatives were not available except in a few cases. The whole series was therefore measured by the bisection method.

Tables 2 and 3 (page 303) give the results of 6 north limb plates and 7 south limb plates. The displacements towards red are larger than was anticipated, the general mean being + 0·0071 A for the north limb and + ·0100 A for the south. There is a close agreement between the different bands, and 3879·79 which gave a zero shift at the centre here shows no anomaly.

The systematic difference between north and south is interesting, and confirms Mr. Pocock's measures. At first sight one might suspect that by some error of adjustment of the solar image an uncorrected rotation component of opposite sign in the two hemispheres affects the results. This is however very improbable, as the error in the estimate of the rotation component would need to be about 0·1 Km/sec., which would involve quite a large deviation of the slit from the position angle of the Sun's axis.

Corrections.—For the sake of completeness I give in tables 4 and 5 the data used for computing the rotation correction and the values of the orbital and diurnal movements of the Earth. In column 3 of these tables ϕ is the apparent latitude or position angle counted from the solar equator of the intersection of the spectrograph slit with the limb. ϕ' and λ are respectively the heliographic latitudes and longitudes of the points photographed. The following columns give the component in the line of sight of the Sun's rotation movement, of the Earth's orbital, and of the Earth's diurnal movement in Km/sec. Column 9 gives the residual motion or algebraic sum of the quantities in the three preceding columns; and in the last column this is expressed in angstroms and is the correction which has been applied to the measured displacements. This correction is in all cases subtractive because of the considerable motion of recession of the Earth from the Sun in April, involving a general shift of the solar lines towards red.

Summary of results.—If we make allowance for the difference between the bisection method of measurement and the more accurate negative on negative method the general means in the limb spectra should be reduced in the ratio 120 to 100. The results for all the spectra measured may therefore be stated as follows :—

	In angstroms.	In Km/sec.
North limb spectra	+ 0·0057	0·44
South limb spectra	+ 0·0080	0·62
Centre of disc	+ 0·0037	0·29

These are the mean shifts for the ten measurable bands in the first head between 3875 and 3883, and it is believed that they represent very approximately the displacements that would be observed were these bands in the Sun freed from all interfering lines of other substances.

It is not claimed that the results here given represent satisfactory mean values of the shifts, because the individual plates both of limb and centre show somewhat discordant values indicating the necessity for measuring a large number of plates preferably taken at different points on the solar limb, before a definite

* The band 3879·8 alone shows a rift due to a partial separation of the more refrangible line of the triplet.

conclusion can be reached. The systematic difference between north and south also points to a certain instability of wave-length in the solar lines.

The result for the south limb plates is remarkably close to the shift corresponding to 0·634 Km/sec. predicted by Einstein and taken by themselves these results must be considered distinctly favourable to the relativity effect. The smaller shift at the centre of the disc is readily explained by an outward radial movement of the solar gases which might produce a partially compensating shift towards violet at the centre. But Fowler has expressed the view that any rising movement on the Sun must be compensated by a downward motion, and that the descending gases would be more likely to produce absorption lines than the hotter ascending gases. Against this however we may argue that the gases which are in a state of the most extreme tenuity are in reality driven out from the Sun continuously into the coronal region by light pressure, as appears to be the case in the eruptive prominences, so that no downward compensating motion would be observed.

These results appear to be in serious disagreement with those of St. John who concluded that "within the limits of error there is no evidence of a displacement either at the centre or at the limb of the Sun of the order of 0·008 A as required by the principle of relativity." St. John did not measure the displacement of the bands in the first head at the limb of the Sun, and his conclusion is largely based on the mean shift of 17 lines of small intensity which was zero. The question whether the carbon arc band lines (which are unaffected by pressure or pole effect in the arc) do or do not confirm Einstein's prediction resolves itself into the question whether we should place more reliance on the strongly marked triplet bands or on the single weak lines measured by St. John, and this again raises the question whether the strong and weak lines if freed from all interference by lines of other substances would actually be shifted by equal amounts.

In the case of iron the shift of the lines at the centre of the disc or in general sunlight depends largely on intensity, the strong lines being much more shifted than the weak; but at the limb the shifts are approximately equalised, so that the great difference of shift between the stronger and weaker lines of the carbon arc at the limb is anomalous and needs further investigation.

I have pleasure in acknowledging the very material aid rendered in this research by First Assistant A. A. Narayana Ayyar, B.A. Most of the measures of limb spectra were made by him and he also performed all of the computations necessary for determining the corrections.

THE OBSERVATORY,
KODAIKANAL,
May 1920.

J. EVERSHED,
Director, Kodaikanal and Madras Observatories.

TABLE I.—CENTRE OF DISC — ARC IN A/10,000.

Mean Wave length of band Rowland.	1918 March 26d 11h 50m & 30d 9h 42m correction —40.	1918 March 29d 11h 43m & 29d 11h 47m correction —54.	1918 April 1d 10h 56m & 1d 11h 02m correction —44.	1918 April 2d 11h 25m & 2d 12h 01m correction —56.	1918 April 3d 9h 51m & 3d 9h 56m correction —23.	1918 April 6d 11h 01m & 6d 11h 06m correction —45.	Means.
3876·59	+ 43	+ 46	+ 25	+ 26	...	0	+ 28
3877·62	+ 46	+ 34	+ 34	+ 16	...	− 04	+ 25
3879·39	+ 94	+ 68	+ 36	+ 19	+ 35	+ 09	+ 43
3879·79	+ 24	+ 08	− 04	− 05	− 13	− 32	− 04
3880·17	+ 45	+ 17	+ 38	+ 27	+ 31	+ 12	+ 28
3880·53	+ 61	+ 53	+ 61	64	+ 51	+ 09	+ 50
3880·87	+ 39	+ 53	+ 43	+ 28	+ 31	+ 02	+ 33
3881·20	+ 29	+ 06	+ 23	+ 22	+ 42	− 11	+ 18
3881·49	+ 51	+ 25	+ 57	+ 30	+ 49	+ 19	+ 38
3881·78	+ 47	+ 49	+ 64	+ 37	+ 68	+ 15	+ 47
Means ...	+ 0·0048	+ 0·0036	+ 0·0038	+ 0·0026	+ 0·0037	+ 0·0002	+ 0·0031

General Mean omitting April 6 + 0·0037 A.

TABLE II.—NORTH LIMB — ARC IN A/10,000.

—	1918 April 6d 10h 13m correction —34.	1918 April 9d 10h 19m correction —32.	1918 April 9d 10h 32m correction —26.	1918 April 10d 10h 24m correction —28.	1918 April 11d 10h 19m correction —29.	1918 April 17d 10h 10m correction —30.	Means.
3876·59	+ 47	+ 71	+ 59	+ 63	+ 115	+ 57	+ 69
3877·62	+ 99	+ 61	+ 61	+ 78	+ 69	+ 57	+ 71
3879·39	+ 67	+ 50	+ 117	+ 82	+ 116	+ 49	+ 80
3879·79	+ 22	+ 68	+ 98	+ 113	+ 147	+ 53	+ 83
3880·17	+ 33	+ 66	+ 70	+ 105	+ 124	+ 76	+ 79
3880·53	+ 52	+ 64	+ 78	+ 78	+ 83	+ 35	+ 65
3880·87	+ 70	+ 33	+ 57	+ 59	+ 101	+ 70	+ 65
3881·20	+ 26	+ 25	+ 43	+ 36	+ 77	+ 43	+ 42
3881·49	+ 81	+ 82	+ 95	+ 89	+ 116	+ 115	+ 96
3881·78	+ 63	+ 44	+ 78	+ 66	+ 101	+ 34	+ 64
Means ...	+ 0·0056	+ 0·0056	+ 0·0076	+ 0·0077	+ 0·0105	+ 0·0059	+ 0·0071

TABLE III.—SOUTH LIMB — ARC IN A/10,000.

—	1918 April 6d 10h 04m correction —24.	1918 April 9d 10h 12m correction —33.	1918 April 9d 10h 38m correction —54.	1918 April 10d 10h 17m correction —36.	1918 April 11d 10h 12m correction —32.	1918 April 16d 11h 41m correction —107.	1918 April 17d 10h 01m correction —21.	Means.
3876·59	+ 45	+ 112	+ 102	+ 143	+ 175	+ 105	+ 88	+ 110
3877·62	+ 78	+ 128	+ 147	+ 115	+ 132	+ 83	+ 108	+ 113
3879·39	+ 31	+ 89	+ 96	+ 126	+ 152	+ 91	+ 107	+ 99
3879·79	+ 37	+ 57	+ 144	+ 128	+ 141	+ 83	+ 63	+ 93
3880·17 ..	+ 21	+ 89	+ 101	+ 86	+ 155	+ 86	+ 81	+ 88
3880·53	+ 76	+ 80	+ 121	+ 142	+ 232	+ 96	+ 57	+ 115
3880·87	+ 105	+ 78	+ 94	+ 112	+ 119	+ 52	+ 112	+ 96
3881·20	+ 30	+ 69	+ 25	+ 74	+ 63	+ 115	+ 73	+ 64
3881·49	+ 87	+ 62	+ 119	+ 146	+ 187	+ 122	+ 88	+ 116
3881·78	+ 113	+ 64	+ 110	+ 118	+ 125	+ 113	+ 91	+ 105
Means ...	+ 0·0062	+ 0·0083	+ 0·0106	+ 0·0119	+ 0·0148	+ 0·0095	+ 0·0086	+ 0·0100

TABLE IV.—NORTH LIMB CORRECTIONS.

Date.	Hour.	ϕ	ϕ'	λ	Rotation.	Orbital.	Diurnal.	Residual.	A.
1918.	H. M.	°	°	°					
April 16	10 13	89·8	...	...	...	+ 0·507	− 0·245	+ 0·262	− 0·0034
" 9	10 19	89·1	70	2 E	− 0·017	+ 0·499	− 0·232	+ 0·250	− 0·0032
" 9	10 32	86·2	70	11 E	− 0·090	+ 0·499	− 0·210	+ 0·199	− 0·0026
" 10	10 24	87·8	70	7 E	− 0·058	+ 0·495	− 0·223	+ 0·214	− 0·0028
" 11	10 19	88·2	70	5 E	− 0·041	+ 0·492	− 0·230	+ 0·221	− 0·0029
" 17	10 10	89·6	...	...	...	+ 0·471	− 0·242	+ 0·229	− 0·0030

TABLE V.—SOUTH LIMB CORRECTIONS.

Date.	Hour.	ϕ	ϕ'	λ	Rotation.	Orbital.	Diurnal.	Residual.	A
1918.	H. M.	°	°	°					
April 6	10 04	87·6	81	17 E	− 0·058	+ 0·507	− 0·259	+ 0·190	− 0·0024
" 9	10 12	89·7	...	...	...	+ 0·499	− 0·244	+ 0·255	− 0·0033
" 9	10 38	84·9	81	35 W	+ 0·115	+ 0·499	− 0·199	+ 0·415	− 0·0054
" 10	10 17	89·2	82	7 W	+ 0·021	+ 0·495	− 0·235	+ 0·281	− 0·0036
" 11	10 12	90·0	...	...	...	+ 0·492	− 0·242	+ 0·250	− 0·0032
" 16	11 41	71·8	70	65 W	+ 0·429	+ 0·473	− 0·076	+ 0·826	− 0·0107
" 17	10 01	87·7	80	14 E	− 0·055	+ 0·471	− 0·257	+ 0·159	− 0·0021

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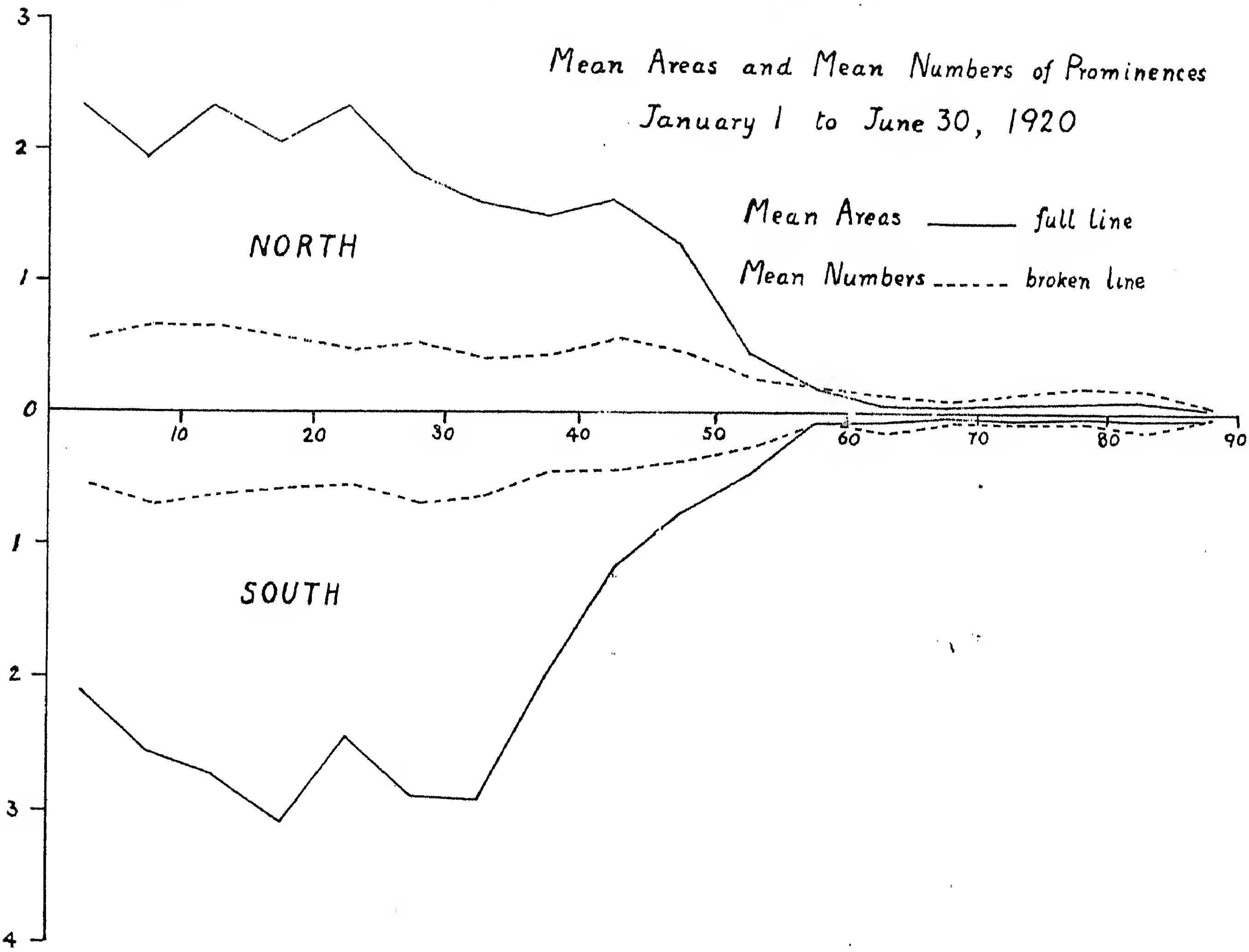
Kodaikanal Observatory.

BULLETIN No. LXV.

SUMMARY OF PROMINENCE OBSERVATIONS FOR THE FIRST HALF OF THE YEAR 1920.

The distribution of prominences observed and photographed during the half-year ending 30th June 1920, is represented in the accompanying diagram, in which the full line gives the mean daily areas and the broken line the mean daily numbers for each zone of 5° of latitude. The ordinates represent tenths of a square minute of arc for the full line and numbers for the broken line. The means are corrected for incomplete or imperfect observations, the total of 168 days being reduced to 159 effective days.



The distribution is very similar to that during the second-half of 1919, except that there is a slight reduction in activity in the belt 30°—40° in the northern hemisphere.

The mean daily areas and numbers corrected for imperfect observations are given below :—

	Mean daily areas (square minutes).	Mean daily numbers.
North	1·99	6·76
South	2·34	6·47
Total ...	4·33	13·23

Compared with the previous half-year, areas show an increase of 12 per cent in the southern hemisphere but practically no change in the northern, and numbers show a general increase amounting to 17 per cent. Areas again show a preponderance in the southern hemisphere and numbers in the northern. The southern prominences were also slightly brighter than the northern.

The monthly, quarterly and half-yearly areas and numbers and the mean height and extent of the prominences are given in table I. The unit of area is 1 square minute of arc.

TABLE I.—ABSTRACT FOR THE FIRST-HALF OF 1920.

Month.	Number of days (effective).	Areas.	Numbers.	Daily Means.		Mean height.	Mean extent.
				Areas.	Numbers.	″	°
January	25	109·3	323	4·37	12·9	35·4	2·94
February	29	112·0	394	3·86	13·6	31·8	2·90
March	30	131·8	382	4·39	12·7	32·9	3·55
April	27	126·8	364	4·70	13·5	30·6	3·10
May	28	135·2	386	4·83	13·8	32·1	3·20
June	20	74·1	251	3·70	12·6	31·5	2·87
First quarter	84	353·1	1099	4·20	13·1	33·2	3·13
Second quarter	75	336·1	1001	4·48	13·3	31·4	3·08
First half-year	159	689·2	2100	4·33	13·2	32·4	3·11

Although the mean height and extent show a decrease compared with the latter half of 1919, the increase of 17 per cent in mean daily numbers has resulted in an increase of the mean area.

Distribution east and west of the sun's axis.

There is a western preponderance both of areas and numbers but not so large as in the latter half of 1919.

1920 January to June.	East.	West.	Percentage east.
Total number observed	1014	1086	48·29
Total areas in square minutes	335·8	353·4	48·72

The western prominences were also slightly brighter than the eastern.

Metallic Prominences.

Eighty-six metallic prominences were observed in the half-year. Details of these prominences are given in the following table :—

TABLE II.—*List of Metallic Prominences observed at Kodaikanal from January to June 1920.*

Date.		Hour I.S.T.		Base.	Latitude.		Limb.	Height.	Lines.
					North.	South.			
1920.		H.	M.	°	°	°		"	
January	9	8	42	8		22	W	50	4924·1, 5018·6, b_1, 5234·8, 5316·8, D_1, D_2.
	12	8	55	8	52		E	50	b_1, b_2, b_3, D_1, D_2
	14	9	2	3	26·5		E	60	b_1, b_2, b_3, b_4, D_1, D_2.
	15	8	50		30		E	60	4924·1, b_1, b_2, b_3, b_4, 5316·8, D_1, D_2.
	16	9	20	2		31	E	45	b_1, b_2, b_3, D_1. D_2.
	17	8	50		46		E	40	b_1, b_2, b_3, b_4, 5316·8, D_1, D_2.
	17	9	8	3		29·5	E	60	b_1, b_2, b_3, b_4, 5316·8, D_1, D_2.
	18	9	4	3		28·5	E	60	b_1, b_2, b_3, b_4, D_1, D_2.
	22	9	20	4		10	E	60	b_1, b_2, b_3, b_4, 5316·8, D_1, D_2, 6677 and 7065.
	22	9	35			20	E	30	b_1, b_2, b_3, b_4, 5316·8, D_1, D_2.
	24	8	52	11		3·5	W	50	4924·1, b_1, b_2, b_3, b_4, 5316·8, D_1, D_2, 6677 and 7065.
	30	8	42	12		18	W	60	4924·1, 5016, b_1, b_2, b_3, b_4, 5234·8, 5276·2, 5316·8, 5535·1, D_1, D_2, 6677 and 7065.
	31	9	10	4		29	W	20	4924·1, b_1, b_2, b_3, b_4, 5316·8, D_1, D_2.
	31	8	44	2	40·5		W	20	b_1, b_2, b_3, b_4, 5316·8, D_1, D_2.
February	3	8	51	10	Equator		W	40	4924·1, 5016, b_1, b_2, b_3, b_4, 5316·8, D_1, D_2, 6677 and 7065.
	4	9	15	3		22·5	E	40	b_1, b_2, b_3, b_4, D_1, D_2,
	4	9	18	6		36	E	90	b_1, b_2, b_3, b_4, D_1, D_2.
	4	8	50			6	W	35	4924·1, b_1, b_2, b_3, b_4, 5316·8, D_1, D_2, 6677 and 7065.
	5	9	17	2	42·5		E	50	b_1, b_2, b_3, b_4, D_1, D_2.
	5	9	20	5		20·5	E	30	b_1, b_2, b_3, b_4, 5316·8, D_1, D_2.
	5	9	25	5		33·5	E	95	b_1, b_2, b_3, b_4, 5316·8, D_1, D_2.
	6	8	52			36	E	70	D_1, D_2.
	8	8	50	2	35·5		E	20	b_1, b_2, D_1, D_2.
	8	9	5	2	11		E	60	b_1, b_2, b_3, b_4, 5316·8, D_1, D_2.
	9	8	45	14	5		E	100	4924·1, 5016, 5018·6, b_1, b_2, b_3, b_4, 5234·8, 5316·8, 5363·0, 5397·3, 5535·1, D_1, D_2, 6677 and 7065.
	11	9	10	2	21		E	15	b_1, b_2, b_3, b_4, 5316·8, D_1, D_2.
	11	8	56	2		9	W	15	b_1, b_2, b_3.
	12	9	20	10	Equator		E	50	b_1, b_2, b_3, b_4, 5316·8, D_1, D_2.
	13	8	35	2		31	E	30	b_1, b_2, b_3, b_4, 5316·8, D_1, D_2.
	13	8	22	2	11		W	35	4924·1, 5018·6, b_1, b_2, b_3, b_4, 5316·8, D_1, D_2, 6677.
	14	8	25			6	E	40	b_1, b_2, b_3, b_4, D_1, D_2.
	16	8	23	10		5	E	120	b_1, b_2, b_3, b_4, 5316·8, D_1, D_2.
	17	8	50			7	E	10	4924·1, b_1, b_2, b_3, b_4, 5316·8, D_1, D_2, 6677 and 7065.
	17	9	10		20		W	60	b_1, b_2.
	18	9	20	3	33		E	35	b_1, b_2, b_3.
	19	9	10			37	W	40	b_1, b_2, b_3, b_4, 5316·8, D_1, D_2.
	23	8	38	1	9·5		W	15	4924·1, 5018·6, b_1, b_2, b_3, b_4, 5234·8, 5276·2, 5284·2, 5316·8, 5363·0, 5535·1, D_1, D_2.
	27	8	49		7		E	55	b_1, b_2, b_3, b_4, D_1, D_2.
	27	8	39	4		30	W	40	b_1, b_2, b_3, b_4, 5316·8, D_1, D_2.
	28	8	55	10		28	W	45	b_1, b_2, b_3, b_4, 5316·8, D_1, D_2, 7065.
	29	8	52	12		30	W	25	b_1, b_2, b_3, b_4. 5316·8, D_1, D_2.
	29	8	40	3	15·5		W	25	4924·1, 5016, 5018·6, b_1, b_2, b_3, b_4, 5208·7, 5234·8, 5276·2, 5316·8, D_1, D_2, 6677 and 7065.
March	2	9	8		18		E	30	b_1, b_2, b_3, b_4, 5316·8, D_1, D_2.
	3	8	45	4	15		E	40	b_1, b_2, b_3, b_4, 5316·8, D_1, D_2.
	3	8	35	2		6	W	15	4924·1, b_1, b_2, b_3, b_4, 5316·8, D_1, D_2, 6677 and 7065.
	6	8	20	4		7	W	65	4924·1, 5016, b_1, b_2, b_3, b_4, 5234·8, 5276·2, 5284·2, 5316·8, 5363·0, D_1, D_2, 6677 and 7065.
	7	8	48	5	14·5		E	25	b_1, b_2, b_3, b_4, 5316·8, 5363·0, D_1, D_2.
	7	9	0			12	W	15	4924·1, 5016, 5018·6, b_1, b_2, b_3, b_4, 5316·8, D_1, D_2.
	7	9	3			7	W	10	b_1, b_2, b_3, b_4, 5316·8, D_1, D_2.

Date.		Hour I.S.T.	Base.	Latitude.		Limb.	Height.	Lines.
				North.	South.			
1920.		H. M.	°	°	°		"	
March	11	8 35			20	E	65	b_1, b_2, b_3, b_4, 5316·8, D_1, D_2.
	12	8 42	5		29·5	E	20	b_1, b_2, b_3, b_4, D_1, D_2.
	13	8 50	11		28·5	E	40	b_1, b_2, b_3, b_4, 5316·8, D_1, D_2.
	13	8 38	16	17		W	50	b_1, b_2, b_3, b_4, 5316·8, D_1, D_2.
	14	8 29		4		E	35	b_1, b_2, b_3, b_4, D_1, D_2.
	14	8 26			9	E	35	b_1, b_2, b_3, b_4, D_1, D_2.
	14	8 42	3	17·5		W	95	4924·1, 5016, 5018·6, b_1, b_2, b_3, b_4, 5234·8, 5276·2, 5284·2, 5316·8, 5363·0, 5535·1, D_1, D_2, 6677 and 7065.
	15	8 49	5		5·5	E	70	4922·4, 4924·1, 5016, 5018·6, b_1, b_2, b_3, b_4, 5234·8, 5269·8, 5276·2, 5284·2, 5316·8, 5363·0, 5397·3, 5405·9, 5535·1, D_1, D_2, 6677 and 7065.
	15	8 33	4	10		W	120	4924·1, 5018·6, b_1, b_2, b_3, b_4, 5234·8, 5276·2, 5284·2, 5316·8, 5363·0, D_1, D_2, 6677 and 7065.
	18	8 39	13	2·5		W	220	b_1, b_2, b_3, b_4, 5316·8, D_1, D_2.
	24	9 22	8		11	W	55	b_1, b_2, b_3, b_4, 5316·8, D_1, D_2.
	25	8 58	1		9·5	W	30	b_1, b_2, b_3, b_4, 5316·8, D_1, D_2.
	28	8 45	17		4·5	W	120	4924·1, 5018·6, b_1, b_2, b_3, b_4, 5316·8, 5363·0, D_1, D_2, 6677 and 7065.
	30	8 43	2	23		E	15	b_1, b_2, b_3, b_4, 5316·8, D_1, D_2.
	30	8 34	2		19	W	30	b_1, b_2, b_3, b_4, 5316·8, D_1, D_2.
April	2	9 22	5	6·5		E	30	b_1, b_2, b_3, D_1, D_2.
	5	8 40	6		11	E	40	b_1, b_2, b_3, b_4, 5316·8, D_1, D_2.
	7	8 55			8	E	80	b_1, b_2, b_3, b_4, 5316·8, D_1, D_2.
	10	8 30			4	E	15	4924·1, 5018·6, b_1, b_2, b_3, b_4, 5234·8, 5276·2, 5284·2, 5316·8, 5363·0, D_1, D_2, 6677 and 7065.
	10	8 30			9·5	E	20	4924·1, 5018·6, b_1, b_2, b_3, b_4, 5234·8, 5276·2, 5284·2, 5316·8, 5363·0, D_1, D_2, 6677 and 7065.
	11	8 50		10		W	90	b_1, b_2, b_3, b_4, 5316·8, 5363·0, D_1, D_2.
	22	8 38	2		17	W	30	b_1, b_2, b_3, b_4, 5316·8, 5363·0, D_1, D_2.
	25	8 48			17	W	75	4924·1, b_1, b_2, b_3, b_4, 5316·8, D_1, D_2.
May	7	8 56	11		13·5	E	65	4924·1, b_1, b_2, b_3, b_4, 5316·8, D_1, D_2, 7065.
	7	9 2	5		28·5	E	50	b_1, b_2, b_3, b_4, 5316·8, D_1, D_2.
	8	10 36	12		15	E	80	b_1, b_2, b_3, b_4, 5316·8, D_1, D_2.
	8	10 43	3		28·5	E	40	b_1, b_2, b_3, b_4, D_1, D_2.
	9	9 6	7	20·5		E	60	4924·1, b_1, b_2, b_3, b_4, 5316·8, D_1, D_2, 6677 and 7065.
	16	8 40		13		W	10	b_1, b_2, b_3, b_4, 5316·8, D_1, D_2.
	16	8 35	5	17·5		W	25	5018·6, b_1, b_2, b_3, b_4, 5208·5, 5269·8, 5276·2, 5316·8, 5363·0, D_1, D_2, 6677 and 7065.
	17	8 8			11	W	60	4924·1, 5016, 5018·6, b_1, b_2, b_3, b_4, 5234·8, 5276·2, 5316·8, D_1, D_2, 6677 and 7065.
	21	9 24	6		13	W	40	b_1, b_2, b_3, b_4, 5316·8, D_1, D_2.
	30	8 40	3	22·5		E	20	b_1, b_2, b_3, b_4, 5316·8, D_1, D_2.
	30	8 52	1	14·5		E	70	4924·1, 5016, b_1, b_2, b_3, b_4, 5316·8, D_1, D_2.
June	1	9 35	8	30		E	60	b_1, b_2, b_3, b_4, 5316·8, D_1, D_2.
	11	9 16		11		E	15	b_1, b_2, b_3, D_1, D_2.
	12	9 12		14		W	35	5016, b_1, b_2, b_3, b_4, 5316·8, D_1, D_2, 6677 and 7065.

The metallic prominences recorded above were distributed in latitude as follows :—

—	1°–30°.	31°–60°.	Mean latitude.	Extreme latitudes.
			°	° °
North	29	6	19·6	1 and 52
South	43	6	17·8	3·5 and 37
Equator	2	...	...	...

Fifty were on the east limb and 36 on the west.

Displacements of the hydrogen lines.

Particulars of the displacements observed in the chromosphere and prominences are given in the following table :—

TABLE III.

Date.		Hour I.S.T.		Latitude.		Limb.	Displacements.			Remarks.
				North.	South.		Red.	Violet.	Both ways.	
1920.		H.	M.	°	°		A	A	A	
January	9	8	40	53		E	Slight			
	9	8	33		27	E	1	0·5		To red at top; to violet at base.
	10	8	31	82·5		W		Slight		1 A to violet at 8^h 51^m.
	10	8	31	84·5		W	Slight			Not seen at 8^h 51^m.
	12	8	40	61·5		W		Slight		
	13	8	35	79		W		Do.		
	14	8	48	47·5		E	1			
	14	9	15		66·5	E		Slight		
	14	8	42	34		W		1·5		
	14	8	40	53		W		Slight		No prominence.
	15	8	58	7		E	2			
	15	8	45		11	W		0·5		
	16	8	58	31		W		Slight		
	17	8	34	84·5		E		0·5		
	17	8	52	35·5		E		1		At top.
	18	8	40	10		W	1·5			Do.
	18	8	35	64·5		W		Slight		
	20	8	44	59·5		W		0·5		
	22	9	20		11	E	1·5			
	22	9	2	83·5		W	0·5			
	23	8	24		20	W		2		
	24	8	44	78·5		E	0·5			
	24	9	3		40	W	2			At top.
	24	8	52	1·5		W	3			
	27	9	13	8		W	1			
	27	9	10	58·5		W	1·5			
	28	8	50	7·5		W		1		At base.
	29	9	10		46	W		0·5		Do.
	29	9	0		14·5	W		1·5		
	30	8	30		18	E	1			
	30	8	42		19	W			Slight	
	31	9	10		29	W		1·5		At base.
February	2	8	38		52	W		Slight		
	3	9	10		8	W	1·5			
	3	8	51	Equator		W	3	2		To red at top; to violet at base. 5 A to violet at base at 9^h 15^m.
	3	8	50		5	W	3	1·5		To red at top; to violet at base.
	4	8	50		6	W	2			At top.
	4	8	44	43·5		W	1·5			
	4	8	40	56·5		W		Slight		
	5	8	55	77·5		E		Do.		
	5	9	6		7·5	W	3	0·5		To red at top; to violet at base. The violet displacement was 2 A at 9^h 10^m.
	5	8	58	43·5		W	1			
	6	8	49		22	E	Slight			
	7	8	47	8		E	Do.			
	8	8	42	70		W		Slight		
	9	8	31	18		E	Slight			
	9	8	45	5		E			0·5	
	9	8	50		21·5	E	1·5			
	10	8	33	75·5		W	Slight			
	11	8	40	65		E	Do.			
	11	8	45	82		W	1			
	12	8	58	35·5		E	Slight			
	12	9	20	Equator		E	2·5			At top.
	13	8	35		31	E		2		Do.
	13	8	45		40	W		1·5		Do.
	13	8	22	11		W	2	1		To red at top; to violet at base.
	13	8	16	25		W		0·5		

Date.		Hour I.S.T.		Latitude.		Limb.	Displacements.			Remarks.
				North.	South.		Red.	Violet.	Both ways.	
1920.		H.	M.	°	°		A	A	A	
February	15	9	6		6	W	1·5	1		To red at top; to violet at base.
	16	8	18	18		E	0·5			
	16	8	10	57·5		W		Slight		
	17	8	50		7	E	2			
	17	9	15	78·5		W	0·5			
	18	8	50	61		W	Slight			
	19	8	48	57·5		E		Slight		
	20	9	15		13·5	E	1			
	20	9	3	7		W	1·5			
	20	8	48	17		W	2·5			At top.
	21	8	33	49·5		E		1		
	21	8	33	74·5		W		Slight		At base.
	22	8	23		18·5	E		Do.		
	22	8	18		7	W	Slight			
	23	8	31		1	W	1			
	24	8	40	69		E		Slight		
	24	8	50		17	E	1·5			At top.
	24	8	46	20		W	1·5			Do.
	26	8	30	47		E	1·5			Do.
	26	9	37		13	W		2		Do.
	27	8	32	Axis		...		Slight		
	27	8	46	32·5		E	0·5			
	27	8	38		22·5	W	0·5			
	28	8	42	78·5		E	1·5			
	28	8	38	69		E		Slight		
	28	8	35	44·5		E		Do.		
	28	8	45	60		W	Slight			
March	2	8	36	67		E	1			
	2	9	0		64	W		0·5		
	3	8	28	74·5		E	Slight			At top.
	3	8	45	17		E		0·5		At base.
	3	8	35		6	W		1·5		
	4	8	30	70		E	Slight			
	6	8	20		7	W		Slight		
	7	8	36	82		E	1			
	7	9	8	4·5		E	5			At top.
	7	9	0		12	W	2			At base.
	8	9	0		64	W		Slight		
	9	8	52	54·5		W		Do.		
	10	8	36		78·5	E	0·5			
	10	8	27	13·5		W	Slight			
	11	8	45	52·5		W		Slight		
	12	8	26	82		E		Do.		
	12	8	34	41		W		0·5		
	12	8	32		6	W	Slight			
	13	8	46	40·5		E	Do.			
	13	8	47	19		E	Do.			
	14	8	33	55		E			Slight	
	14	8	27		9	E		0·5		
	14	8	36	7		W		Slight		
	14	8	42	10		W	2			
	15	8	49	Equator		E		2		
	15	8	49		4	E	0·5	2		To red at top; to violet at base.
	15	8	33	13		W			2	
	16	8	40		4	E			1·5	
	16	8	36		32·5	E		0·5		
	16	8	44	74·5		W	1	1·5		To red at top; to violet at base.
	17	8	22	83		E		Slight		
	17	8	32	6·5		E	0·5			At top.
	17	8	34		4·5	E			Slight	
	18	8	23		73	W	Slight			
	18	8	38		2	W		Slight		At top.
	19	8	15	46·5		E		Do.		
	19	8	34		22	E	2			
	19	8	26		11	W		Slight		At top.
	21	8	27	30		E	Slight			

Date.		Hour I.S.T.		Latitude.		Limb.	Displacements.			Remarks.
				North.	South.		Red.	Violet.	Both ways.	
1920.		H.	M.	°	°		A	A	A	
March	21	8	25	2		E	Slight			
	21	8	35	81·5		W		Slight		
	22	8	56	75·5		E		Do.		
	22	8	55	58		E		Do.		
	23	9	15	10·5		E	1			
	24	9	10	42·5		E	1	1·5		To red at top; to violet at base.
	25	9	15	11		E		1·5		At top.
	26	8	42	47·5		E		Slight		
	26	8	53		7	W	5	1		To red at top; to violet at base.
	27	8	13	16·5		E			Slight	
	27	8	20		45·5	E		0·5		
	27	8	22		60·5	E	0·5			
	27	8	13		16	W			Slight	
	27	8	31		5	W	Slight	Slight		To red at base and top and to violet over the middle of prominence.
	27	8	28	2·5		W	2	1		To red at top; to violet at base.
	28	8	38	69		E		1		
	28	8	40		4·5	W	3	2		To red at top; to violet at base.
	30	8	18	Axis		...		Slight		
	30	8	15	41		E	0·5			
	30	8	46	11·5		E	1·5			At top.
	30	8	48		14·5	E	0·5	1·5		To red at base; to violet at top.
	30	8	26	9		W	0·5			At top.
	30	8	22	75·5		W		2		At top.
April	1	9	0		8	E		0·5		
	2	9	6		6	E	Slight			
	2	8	46	10		W		Slight		
	5	8	40		11	E		Do.		At top.
	5	8	31	26		W		Do.		
	5	8	30	47·5		W			0·5	
	6	8	31		5	E		2		
	6	8	27		50·5	E		2		
	6	8	38	33		W	Slight			
	7	8	35	82		E		0·5		
	7	8	55		5	E	2	1·5		To red at base; to violet at top.
	7	9	3		27	E	1·5			At base.
	9	8	54		45·5	W		Slight		
	9	8	50	23		W			Slight	
	10	8	30		9·5	E		Slight		
	10	8	21		45·5	E	Slight			
	11	8	38	81·5		E		Slight		
	11	9	8	6		E	2			
	11	8	50	14		W	1	1·5		To red at top; to violet at base.
	11	8	50	10		W		1·5		At base.
	11	8	42	58·5		W		Slight		
	12	8	39	10		W	0·5			
	13	8	8		41	W	Slight			
	15	8	40	71		E		0·5		At base.
	16	8	50		43	W		0·5		
	18	8	36	44·5		W		Slight		
	26	8	52	54·5		W		0·5		
	27	8	45		26	W	1·5	1		To red at top; to violet at base.
May	3	9	11		10	E	1·5			
	5	9	22		38	W		1		
	6	8	50	11·5		E		1		At base.
	7	8	33	65		E				Do.
	7	8	42	83		W		0·5		
	9	9	6	20·5		E	1·5			At base.
	9	9	10		21	E	2			
	9	8	56		2·5	W		0·5		At base.
	11	8	32	59		E	0·5			
	12	8	40	71		E	Slight			
	14	8	38	19		W	Do.			
	15	8	54	8		E		Slight		
	15	8	58	16		W	3			

Date.		Hour I.S.T.		Latitude.		Limb.	Displacements.			Remarks.
				North.	South.		Red.	Violet.	Both ways.	
1920.		H.	M.	°	°		A	A	A	
May	16	8	40	13		W		1		At base
	16	8	35	17·5		W	2	1		
	16	8	32	52		W	1			
	17	8	14	10		E		Slight		At top.
	17	8	8		11	W			Slight	
	21	9	24		11	W		Slight		
	24	8	15	48		E		1·5		
	28	8	28	38		E		Slight		
	29	8	38	13·5		E			Slight	
	30	8	40	22·5		E	2			At base.
	30	8	52	14·5		E	1·5			Do.
June	1	9	25	57		W	Slight			
	9	8	15	11		E		Slight		
	10	11	10	57		W	Slight			
	11	9	18		74	E	1			
	12	9	20		58	W		Slight		
	14	8	55		6	E	1·5	1		To red at base ; to violet at top.
	14	9	0		72	W	1			At base.
	16	8	57		50	E		Slight		
	25	8	46	85·5		E		0·5		
	25	9	2	14		E	1·5			At base.
	25	9	15		62	E		1		
	25	9	15		82	E	1			At base.
	25	9	15		82	E	2·5			At top.
	25	8	57		66	W		Slight		
	26	8	18	35		E	Slight			At base.
	26	8	13	6		E	Do.			
	27	8	34	10		E	Do.			

The total number of displacements was 215, of which 3 were on the equator and the rest were distributed as follows :—

Latitude.		North.	South.
1°—30°		52	53
31°—60°		41	15
61°—90°		39	12
	Total ...	132	80

East limb	108
West limb	105
Central meridian	2
Total ...	215

One hundred and eleven were towards the red, and the same number towards the violet ; these include 19 occasions when the displacements were seen to the red and to the violet in different parts of the same prominence. Twelve displacements were both ways simultaneously.

Reversals and displacements on the disc.

One hundred and sixty-four bright reversals of the Hα line, 56 dark reversals of the D_3 line and 110 displacements of the Hα line were recorded during the half-year all of which represent an increase on the latter half of 1919. Their distribution is shown below :—

	North.	South.	East.	West.
Bright reversals of Hα	88	76	82	82
Dark reversals of D_3	24	32	25	31
Displacements of Hα	55	55	63	47

Seventy-nine of the displacements were towards the red, 28 towards the violet and 3 both ways simultaneously.

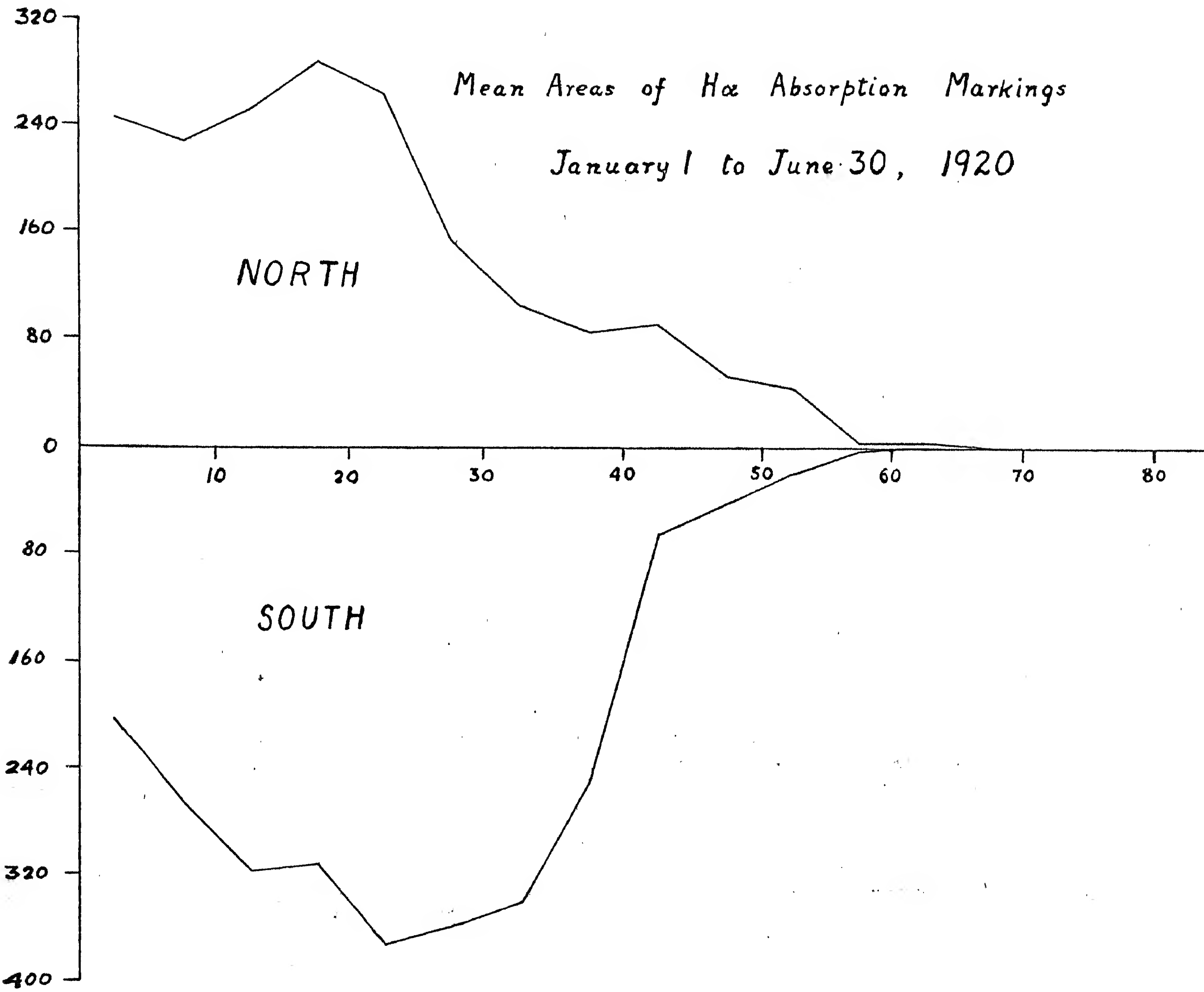
Prominences projected on the disc as absorption markings.

Photographs of the sun's disc in Hα light were obtained on 154 days counted as 146 effective days. The mean daily areas in millionths of the sun's visible hemisphere, corrected for foreshortening, and the mean numbers are given below :—

	Areas.	Numbers.
North	1820	11·8
South	2555	13·9
Total ...	4375	25·7

As in the case of prominences, absorption markings show an increase on the latter half of 1919 ; the increase is greater for the southern hemisphere than for the northern.

The distribution in latitude is represented in the accompanying diagram.



The activity is small in latitudes higher than 60° as in the case of prominences; the maximum of activity near 20° has broadened in the southern hemisphere and narrowed in the northern compared with the distribution in the latter half of 1919.

There is now a preponderance of markings at the western limb in agreement with prominences at the limb, the percentage east being 48·28 for areas and 49·13 for numbers.

KODAIKANAL OBSERVATORY,
18th August 1920.

T. ROYDS,
Acting Director, Kodaikanal and Madras Observatories.

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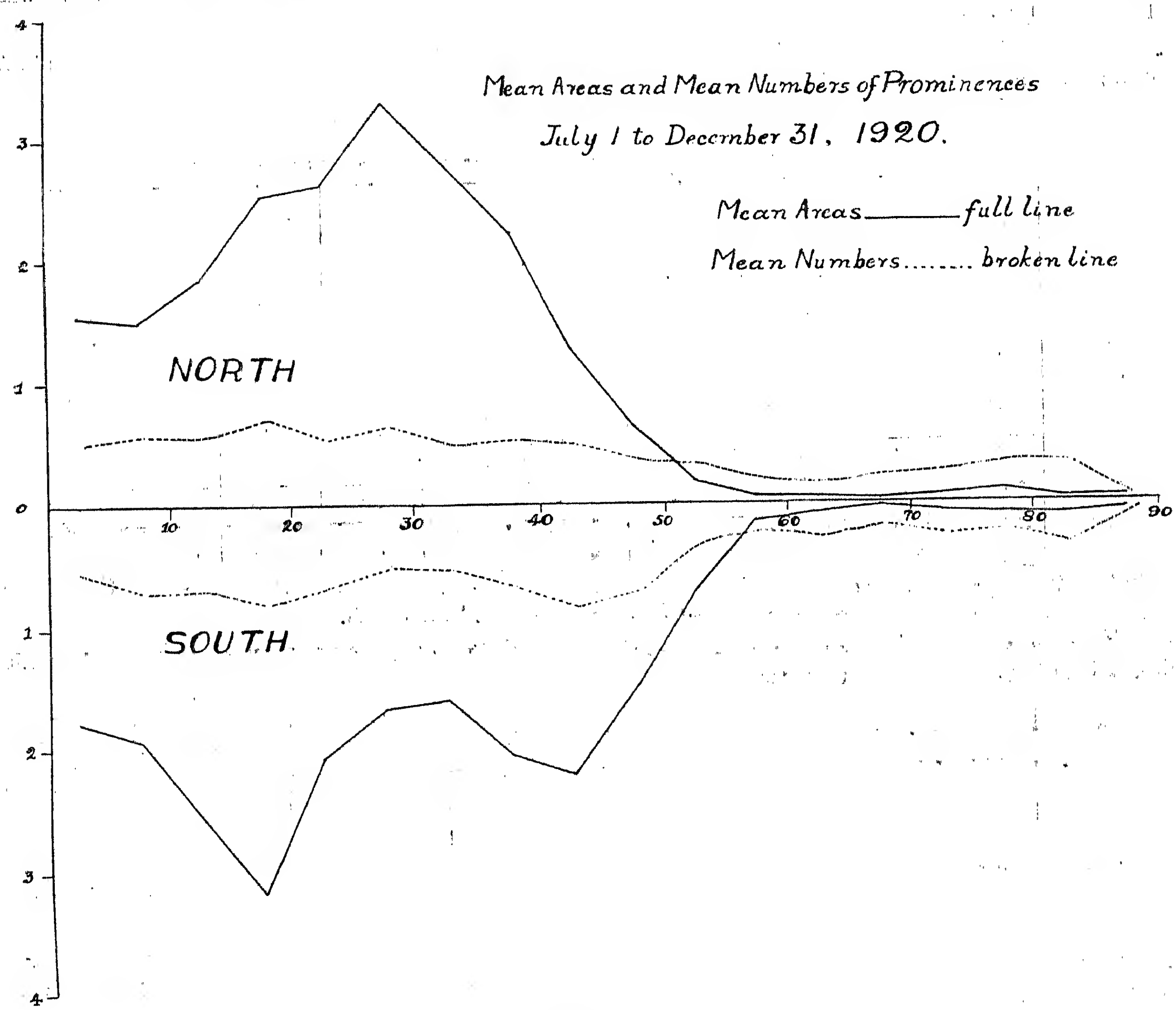
Kodaikanal Observatory.

BULLETIN No. LXVI.

SUMMARY OF PROMINENCE OBSERVATIONS FOR THE SECOND HALF OF THE YEAR 1920.

The distribution of prominences observed and photographed during the half year ending 31st December 1920, is represented in the accompanying diagram, in which the full line gives the mean daily areas and the broken line the mean daily numbers for each zone of 5° of latitude. The ordinates represent tenths of a square minute of arc for the full line and numbers for the broken line. The means are corrected for incomplete or imperfect observations, the total of 143 days being reduced to 129 effective days.



The distribution of areas is markedly different from that in the first half of the year; in the northern hemisphere there is less activity near the equator and in the belt from 40° to 60° but greater activity from 20° to 40°, whilst in the southern there is less activity near the equator and from 20° to 35° but greater activity from 40° to 55°.

The mean daily areas and numbers corrected for imperfect observations are given below :—

	Mean daily areas (square minutes).	Mean daily numbers.
North	2·10	7·41
South	2·17	8·47
Total ...	4·27	15·88

Areas show a decrease of only 1 per cent from the first half of the year with nearly equal activity in the two hemispheres, whilst numbers show a total increase of 20 per cent due to a 10 per cent increase in the northern and 31 per cent increase in the southern. The average brightness of a single prominence was practically the same for both northern and southern hemispheres.

The monthly, quarterly and half-yearly areas and numbers together with the mean height and extent of a prominence are given in table I. The unit of area is 1 square minute of arc.

TABLE I.—ABSTRACT FOR THE SECOND HALF OF 1920.

Month.	Number of days (effective).	Areas.	Numbers.	Daily Means. Areas.	Daily Means. Numbers.	Mean height. "	Mean extent. "
July	18	55·5	246	3·08	13·7	27·8	2·71
August	23	76·1	382	3·31	16·6	27 6	2·36
September	25	104·0	408	4·16	16 3	27·8	3·51
October	21	101·4	368	4·83	17 5	32·1	3·54
November	13	55·9	191	4·30	14·7	31·9	3·95
December	29	157·3	453	5·42	15·6	33·0	3·58
Third quarter	66	235·6	1036	3·56	15·7	27·7	2·98
Fourth quarter	63	314·6	1012	4·99	16·1	32·5	3·64
Second-half-year	129	550·2	2048	4·27	15·9	30·1	3·26

Distribution east and west of the sun's axis.

There is again a western preponderance both of areas and of numbers which in the case of areas is much larger than for the preceding half-year.

1920 July to December.	East.	West.	Percentage east.
Total number observed	972	1076	47·46
Total areas in square minutes	240·7	309·5	43·76

The average brightness of eastern prominences was practically the same as that of western prominences.

Metallic Prominences.

Forty-two metallic prominences were observed in the second half of the year, which is only 50 per cent of the number in the first half. Details of these prominences are given in the following table :—

TABLE II.—LIST OF METALLIC PROMINENCES OBSERVED AT KODAIKANAL, JULY TO DECEMBER 1920.

Date.		Hour I.S.T.		Base.	Latitude.		Limb.	Height.	Lines.
					North.	South.			
1920.		H.	M.	°	°	°		"	
July	4	8	26	4	12		W	65	4924·1, b_1, b_2, b_3, b_4, 5316·8, D_1, D_2, 6677, 7065.
	4	8	22	4	23		W	30	b_1, b_2, b_3, b_4, 5316·8, D_1, D_2, 6677.
	17	8	38	9	12·5		E	40	b_1, b_2, b_3, b_4, 5316·8, D_1, D_2.
	21	9	0	2	Equator		E	15	b_1, b_2, b_4, D_1, D_2.
	27	9	12	1		13·5	E	60	b_1, b_2, b_3, b_4, D_1, D_2.
August	13	8	30	1		17·5	E	15	b_1, b_2, b_3, b_4, 5316·8, D_1 D_2, 6677, 7065.
	30	9	20	18	19		W	85	b_1, b_2, b_3, b_4, D_1, D_2.
	31	8	47	6	27		W	70	4924·1, 5018·6, b_1, b_2, b_3, b_4, 5316·8, D_1, D_2.
September	1	8	37	4	30		W	80	4924·1, 5018·6, b_1, b_2, b_3, b_4, 5316·8, D_1, D_2.
	9	9	36	6		14	W	110	4924·1, 5018·6, b_1, b_2, b_3, b_4, 5316·8, D_1, D_2, 6677, 7065.
	12	9	49	29	19·5		E	80	b_1, b_2, b_3, b_4, D_1, D_2.
October	1	8	20	26	3		W	30	4924·1, 5018·6, b_1, b_2, b_3, b_4, 5234·8, 5276·2, 5284·2, 5316·8, 5363·0, 5535·1, D_1, D_2, 6677, 7065.
	18	10	10	1	25·5		E	10	4924·1, D_1, D_2.
	19	8	35	3		13	E	10	b_1, b_2, b_3, b_4, 5316·8, D_1, D_2, 6677.
	20	8	55	6		17	E	120	b_1, b_2, b_3, b_4, D_1, D_2.
	20	8	41			16·5	W	10	4924·1, 5018·6, b_1, b_2, b_3, b_4, 5234·8, 5276·2, 5316·8, 5363·0, 5535·1, D_1, D_2, 6677.
	23	8	40	4		8	W	60	4924·1, 5016, 5018·6, b_1, b_2, b_3, b_4, 5316·8, D_1, D_2, 6677, 7065.
November	2	8	55	3		14·5	E	30	b_1, b_2, b_3, b_4, 5316·8, D_1, D_2.
	30	9	24	1		22·5	E	70	b_1, b_2, b_3, b_4, D_1, D_2.
	30	10	55	5	42·5		W	70	b_1, b_2, b_3, b_4, D_1, D_2.
December	1	9	15	2		14	E	65	b_1, b_2, b_3, b_4, D_1, D_2.
	1	9	10			28	W	90	4924·1, b_1, b_2, b_3, b_4, 5316·8, D_1, D_2.
	2	7	52	1	17·5		E	40	b_1, b_2, b_3, b_4, D_1, D_2.
	2	9	6			11	E	10	b_1, b_2, b_3, b_4, D_1, D_2.
	2	10	25	7	37·5		W	50	4924·1, 5018·6, b_1, b_2, b_3, b_4, D_1, D_2.
	3	8	34	4	41		W	75	4924·1, 5018·6, b_1, b_2, b_3, b_4, 5234·8, 5276·2, 5284·2, 5316·8, 5363·0, D_1, D_2.
	6	8	54	1		10·5	W	20	4924·1, 5016, b_1, b_2, b_3, b_4, 5316·8, D_1, D_2, 6677, 7065.
	7	8	30		18		W	55	4924·1, 5018·6, b_1, b_2, b_3, b_4, 5316·8, D_1, D_2.
	10	8	16	3		24·5	W	25	4924·1, 5018·6, b_1, b_2, b_3, b_4, 5234·8, 5276·2, 5316·8, 5363·0, 5535·1, D_1, D_2.
	11	10	5		19		W	95	4924·1, 5018·6, b_1, b_2, b_3, b_4, 5316·8, D_1, D_2.
	12	9	50	9	37·5		E	75	D_1, D_2.
	12	9	30		72		W	110	b_1, b_2, b_3, b_4, D_1, D_2.
	13	11	50	2	34		E	90	b_1, b_2, b_3, b_4, 5316·8, D_1, D_2.
	13	11	42	2		11	W	90	b_1, b_2, b_3, b_4, 5316·8, D_1, D_2.
	13	11	34	2	18		W	45	b_1, b_2, b_3, b_4, 5316·8, D_1, D_2.
	19	9	12	1		15·5	E	55	b_1, b_2, b_3, b_4, D_1, D_2.
	20	9	0	3	15·5		E	25	4924·1, 5018·6, b_1, b_2, b_3, b_4, 5316·8, D_1, D_2.
	21	9	42	2	19		E	60	b_1, b_2, b_3, b_4, 5316·8, D_1, D_2.
	21	9	51			10	E	60	b_1, b_2, b_3, D_1, D_2.
	26	9	20		4		E	10	b_1, b_2, b_3, b_4, 5316·8, D_1, D_2.
	26	9	8	4		18	W	30	5018·6, b_1, b_2, b_3, b_4, 5316·8, D_1, D_2.
	29	9	45		23		W	25	5018·6, b_1, b_2, b_3, b_4, 5316·8, D_1, D_2.

The metallic prominences recorded were distributed as follows :—

—	...	1° to 30°	31° to 60°	61° to 90°	Mean latitude.	Extreme latitudes.
					°	°
North	...	17	5	1	24·8	3 and 72
South	...	18	...	...	15·5	8 and 25
Equator	1	...	...	...	..	

Twenty were on the eastern limb and 22 on the western.

Displacements of the hydrogen lines.

Particulars of the displacements observed in the chromosphere and prominences are given in the following table :—

TABLE III.

Date.		Hour I.S.T.		Latitude.		Limb.	Displacements.			Remarks.
				North.	South.		Red.	Violet.	Both ways.	
1920.		H.	M.	°	°		A	A	A	
July	4	8	45	15		E	3			
	4	8	26	15		W	4	2		To red at top; to violet at base.
	7	9	38		3·5	E		1·5		
	12	8	46	22·5		E	1			At base.
	12	10	37	14		W		1		
	17	8	38	12·5		E	3	1		To red at top; to violet at base.
	17	8	24		21	W		Slight		
	18	8	46	56·5		E	Slight			
	18	8	30	70·5		W		Slight		At base.
	21	8	52		20	W	Slight			
	21	8	45	70·5		W		Slight		
	21	8	35	83·5		W		0·5		
	22	9	29	8		E	1			
	23	9	25	14		E	Slight			
	27	9	7		72	W		Slight		
	28	8	49		9	E	Slight			
August	6	8	50		4	W	Do.			
	11	8	55		56	W	Do.			
	11	8	48	16		W		Slight		
	12	9	45	24		E	Slight			
	12	9	31		21	E	1·5			
	13	8	38	53		E	Slight			
	13	8	30		17·5	E	1			
	14	11	0		12	E	Slight			
	21	8	27		10	W	Do.			
	26	9	32	70		E		Slight		
	27	8	40		55	W		Do.		
	27	8	40		46·5	W		Do.		
	27	8	25	6		W			1	
	27	8	24	18		W	Slight			
	28	9	11		9·5	E	1			
	28	9	0		26	E		Slight		
	28	9	0		28	E	Slight			
	29	7	26		59·5	E		Slight		
	29	7	40	23		W				
	30	10	0		42·5	W		Slight	Slight	
	30	9	20	19		W	2			
	30	9	12	49·5		W		Slight		
	31	8	35	61		E	Slight			
	31	8	35		18·5	E	Do.			
	31	8	30		43·5	E	1	0·5		To red at base ; to violet at top.
	31	8	38		71·5	W		Slight		
	31	8	47	27		W		Do.		At base.
September	1	8	44	78		W		Do.		
	2	9	57	27·5		E		2		
	2	9	52	11		E.	2			
	2	9	48		15	E	Slight			
	2	9	45		19	E	Do.			
	3	8	39		5·5	W	Do.			
	4	10	25		57·5	E		Slight		
	4	10	28		66	E	Slight			
	5	11	13	7·5		E	Do.			
	6	9	1		17	W	Do.			
	6	8	50	3		W		Slight		
	7	8	27		63	W	Slight			
	7	8	31		14·5	W	1			
	8	8	59	69		E		Slight		At top.
	8	8	53		14·5	W		2		
	8	9	10		14·5	W		Slight		At top.

Date.		Hour I.S.T.		Latitude.		Limb.	Displacements.			Remarks.
				North.	South.		Red.	Violet.	Both ways.	
1920.		H.	M.	°	°		A	A	A	
September	9	11	4	19·5		E	Slight			
	9	11	13		37	E		Slight		
	9	9	29		2	W		Do.		
	9	10	36		13	W		2		
	9	9	37		17	W		Slight		
	9	9	17	15		W	1	2		
	9	9	13	21		W		1		
	9	9	6	31		W	1			
	9	8	53	58·5		W	Slight			
	10	8	55		67	E	3			
	10	8	42		18·5	W	0·5			
	10	8	38	75·5		W		Slight		
	10	8	38	81		W		Do.		
	11	10	51	15		E	Slight			
	11	10	54		1·5	E		Slight		
	11	10	58		17	E		1		
	11	11	2		23	E	Slight			
	11	11	3		36·5	E		1		
	11	10	0		34·5	W		2		
	11	9	57		31·5	W		Slight		
	11	9	52		24	W		1		
	11	9	43		16	W	1			
	11	9	37	4·5		W	Slight.			
	11	9	30	19		W		Slight		
	11	9	24	37		W		Do.		
	11	9	16	49·5		W	Slight			
	12	10	0	81·5		E		Slight		
	12	9	27	28		E	1			
	12	9	23		12	E	1			
	12	9	12		24	E		1		
	12	9	9		29	E	1			At top.
	12	9	7		39	E	1			
	12	10	13		77	W		1		
	12	10	16		70	W		Slight		
	12	10	39	11·5		W	Slight			
	12	10	7	65		W		Slight		
	13	9	8	8		W	Slight			
	16	8	44	10		W		Slight		
	20	9	34		11	E	Slight			
	22	8	30		9	E	Do.			
	23	9	10		3	W	Do.			
	23	9	18		5	W	1			
	23	9	0	18		W		1		
	25	8	49		12·5	E		1		
	25	8	47		28	E	Slight			
	25	8	44		36	E	1			
	25	9	36		7	W	Slight			
	25	9	25	67		W		Slight		
	28	8	25	11		E	Slight			
	29	8	25		80	W		Slight		
	29	8	23		52·5	W	Slight			
	29	8	3	24·5		W	Do.			
October	1	8	50	9		E			Slight	
	1	8	40		19	W	Slight			At top.
	2	9	39		17	W	Do.			
	2	9	11	10		W	Do.			
	3	9	55		2·5	W		Slight		
	3	9	49	21		W	Slight			
	3	9	50	28		W		Slight		
	4	9	4	20·5		W		Do.		
	4	8	58	40		W		Do.		
	8	9	20	42·5		E		1		
	10	9	47	20·5		E	1			
	10	9	46	16		E	Slight			
	10	9	21		18·5	E	1			
	10	9	9		58·5	E	Slight			

Date.	Hour I.S.T.		Latitude.		Limb.	Displacements.			Remarks.
			North.	South.		Red.	Violet.	Both ways.	
1920.	H.	M.	°	°		A	A	A	
October 10	10	8	1·5		W	Slight			
10	10	18	6		W		1		
10	10	22	20		W	Slight			
11	9	20	82		E		1		
11	8	46	4·5		W	Slight			
12	8	42	80		E	3			At top.
12	8	41	63		E	0·5			
12	8	30	21·5		E	Slight			
13	8	38	63·5		E		Slight		
13	8	44	4		E	1			
13	8	32		19	W			Slight	
13	8	31		5	W	Slight			
14	10	4		19	W		Slight		
14	9	36	20		W	Slight			
14	8	42	45·5		W		2		
14	8	37	53·5		W	3			
15	8	44	31·5		E	Slight			
15	8	40		21	E	Do.			
15	8	37		46	E	Do.			
16	10	45		23	E	1	2		
16	10	57		63·5	E	Slight			
16	9	25		5	W	Do.			
16	9	1	26		W	1			At top.
16	8	54		35	W	Slight			Do.
17	9	49	42		E		1		At base.
17	9	32	17		E		Slight		
17	9	24		7	E		1		
17	9	11		22	E	2			
17	9	8		32	E	Slight			
17	9	1		51·5	E	1			
17	10	9		20	W	1			
17	10	30		11	W	1			
18	9	47	83·5		E		Slight		
18	9	53	39		E	1			
18	9	56	25·5		E	2			
18	10	45		30	E		1		
18	9	40		65·5	E	1			
18	9	37		77·5	W		2		
18	9	29		24	W		1		
18	9	15	1		W	Slight			
18	9	10	8		W	1	Slight		
18	9	7	11		W	3	1		
18	9	4	13		W	1			
18	9	3	17		W	Slight			
18	8	52	42·5		W	2			
18	8	47	40·5		W	1			
18	8	50	46·5		W	1			
18	8	44	56·5		W	1			
18	8	43	57·5		W		1		
19	8	32		19	E	Slight			
19	8	42		82	W		1		
19	8	45		3	W	Slight			
20	8	35	51·5		E		Slight		
20	9	0		86	E		2		
20	8	42		20	W	Slight			
20	8	30	66·5		W		Slight		
20	8	30	71·5		W			Slight	
21	8	58	16		W	1			
21	8	55	18		W	Slight			
21	8	47	35·5		W		1		
21	8	45	41		W		Slight		
22	9	28	38		E	5			Eruptive prominence.
23	8	24		28	E	Slight			
23	8	22		39	E	2			
23	8	40		6	W			1	
23	8	50	52·5		W	0·5			
25	9	20	32		W	2	1		
27	9	27		18	W		Slight		

Date.		Hour L.S.T.		Latitude.		Limb.	Displacements.			Remarks.
				North.	South.		Red.	Violet.	Both ways.	
1920.		H.	M.	°	°		A	A	A	
November	2	9	2		83	E		Slight		
	2	9	4		41	W		Do		
	6	9	45		9	E		Do.		At top.
	6	9	20		32·5	W		Do.		
	6	8	56		21	W	Slight			
	6	8	54		17	W	Do.			
	6	8	40	39		W	1	1		To red at top ; to violet at base.
	6	8	42	44		W		1		
	6	8	40	52		W	1			
	6	9	30	68·5		W		Slight		
	7	9	19	48·5		E	1			
	7	9	16	35·5		E		Slight		
	7	9	35		29	W	Slight			
	7	10	11	35		W		1		At base.
	7	10	8	38		W		3		At top.
	8	9	41	26		E	1			At base.
	8	9	40	33		E		2		
	8	9	50		36	E		1		
	8	9	0	6		W		1		
	8	8	56	17		W	Slight			At base.
	8	8	52	26		W	Do.			
	8	9	30	74·5		W	1			
	9	8	25		46	W		Slight		
	10	8	35		45	W		Do.		
	10	8	32		28	W		Do.		
	12	8	53	20		E	0·5			
	30	10	15	0·5		E		3		At top.
	30	9	14		27	E	2			
	30	10	39		40	W		1		
	30	10	55	41		W		1		At top.
	30	11	8	62		W	Slight			
December	1	9	18		33	E	Do.			
	1	9	5	12		W		Slight		
	2	9	30	51		E			Slight	
	2	9	32	24		E	2	3		
	2	8	59		11	E	1			At base.
	2	8	54		22	E	Slight			At top.
	2	8	45		50	E		Slight		
	2	9	48		36	W		1		
	2	10	4		7	W	Slight			
	2	10	6	10		W	2			
	2	10	42	45		W		1		
	4	9	14	41		E		1		
	4	9	11	26		E	1			At base.
	4	9	5	7		E	1			
	4	8	50		29	E			Slight	At base.
	4	8	47		37	E	Slight			Do.
	4	9	23		51	W	Do.			Do.
	4	9	21		39	W	2			
	4	9	56	46·5		W	Slight			
	5	8	52	50		W	1			At top.
	5	8	45	67		W	1			
	6	8	36	67		E		1		At base.
	6	8	40	81		W		Slight		
	7	8	3		22	W		Do.		
	7	8	3		18·5	W		Do.		
	8	8	53		9	E		1		At top.
	8	8	43		22	E		Slight		Do.
	8	8	38		39	E		1		
	8	9	23	6		W		1		
	8	9	27	13		W	3			At top.
	8	9	44	18		W		2		
	9	8	46	89		E		Slight		
	9	9	10		22	E	3			At base.
	10	8	20		62	W		Slight		Do.
	10	8	6	85		W		Do.		

Date.	Hour I.S.T.		Latitude. North.	Latitude. South.	Limb.	Displacements. Red.	Displacements. Violet.	Displacements. Both ways.	Remarks.
1920.	H.	M.	°	°		A	A	A	
December 11	9	7	49		E		2		
11	9	12	36·5		E		2		At base.
11	9	4	27		E		1		
11	9	8	28		E		3		
11	8	53	29		E	3			
11	9	29		32	W	1			
11	10	30	75		W		1		
12	9	42		12	W	2			At base.
12	9	44		15	W	1			At top.
12	9	25	22		W		Slight		
14	9	39	29		E		Do.		
19	9	41	11		E		1		
19	9	40	7		E		2		
20	8	45	85		W		Slight		
21	9	42	11		E	1·5			At base.
21	9	36		16·5	W	1			
21	9	34		7	W		1·5		At base.
21	9	32	32		W	1			
22	9	37	34		E		1		
22	9	46	5·5		E	1			At base.
22	9	20		37·5	W	1			
22	9	15		21	W		Slight		
22	9	0	13		W		Do.		At base.
23	8	54		19	W		Do.		
24	9	4	8		W		2		At base.
25	9	1	13		W	2			At top.
26	9	4	20		W	2			Do.
27	8	26		18	W		1		Do.
28	9	35	55		E		1		
28	9	27	25		E	1			At base.
28	9	7		13	E		Slight		
28	9	51		29	W		1		
28	9	53		20	W		2·5		
28	10	10	33		W	1			
28	10	10	36		W		1		At base.
28	10	10	31		W	Slight			Do.
28	10	13	71		W		Slight		
29	10	10	23		E		2		
29	10	15		12	E	1			
29	10	29		46	E	2			
29	10	31		47	E		1		
29	9	31	32		W	1			
30	9	24	22		E		Slight		
30	9	20	2		E		1		
30	8	59		45	E	Slight			
30	9	50		37	W		2		
31	9	8	76·5		E		1		
31	9	42	8·5		E	1			
31	9	16		39·5	W	1·5			At top.
31	9	32	4		W		3		
31	9	10	85		W		0·5		

The total number of displacements observed was 310, which were distributed as follows :—

Latitude.	North.	South.
1°—30°	88	87
31°—60°	48	40
61°—90°	32	15
Total ...	168	142

East limb	133
West limb	177
Total ...	310

One hundred and sixty-two were towards the red, 150 towards the violet ; these include 10 occasions when the displacements were seen to the red and to the violet in different parts of the same prominence. Eight displacements were both ways simultaneously.

Reversals and displacements on the disc.

One hundred and thirty-four bright reversals of the Hα line, 73 dark reversals of the D_3 line and 59 displacements of the Hα line were recorded during the half-year. Their distribution is shown below :—

	North.	South.	East.	West.
Bright reversals of Hα	58	76	58	76
Dark reversals of D_3	34	39	34	39
Displacements of Hα	28	31	32	27

Forty-five of the displacements were towards the red, 13 towards the violet and 1 both ways simultaneously.

Large Eruptive Prominence of 31st December 1920.

On 31st December 1920 a series of 14 photographs in K light of a large eruptive prominence was obtained by Mr. S. S. Ramaswami Ayyangar. This prominence extended in latitude from + 5°W to − 40°W. Its ascent was probably already in progress when the first photograph was taken at 8^h 4^m. It appeared then in the form of a large arch, the maximum and minimum heights in the middle of the arch being already 290,000 km and 126,000 km, respectively, above the chromosphere. The progress of the prominence consisted, generally speaking, in the ascent of the centre of the arch until at 10^h 15^m the maximum height was 701,000 km. The northernmost branch of the arch remained visible and in contact with the chromosphere throughout whilst the southernmost which was faint at the commencement disappeared after 8^h 52^m. The brightness of the prominence did not suffer much diminution until after 9^h 47^m and although the maximum height was reached at 10^h 15^m, only a faint trace of the lower portions remained in the next photograph at 10^h 37^m. Whilst these changes were in progress, a small prominence between − 37°W and − 41°W, about 17,000 km high, remained visible practically without change, and between − 3°W and − 8°W were low changing prominences probably connected with spot group No. 3651 (latitude − 8°) which passed the western limb on December 30th.

Measures have been made of the motion of this eruptive prominence. In determining the times, allowance has been made for the fact that the different parts of the prominence on the same photograph are not photographed simultaneously.

In the northern branch of the arch the changes in the form were so rapid that identical parts of the prominence could not be recognized in successive photographs. In the more southerly parts, however, recognition of identical parts was possible and measures of the motion of several points have been made. The average velocity varied from 38 km/sec to 77 km/sec for different points and the largest velocity observed in any part was 115 km/sec, whilst there is evidence of only slight acceleration the largest being only 7·4 km/sec/sec. These are very much smaller than the velocities and accelerations in the prominence of 26th May 1916 described in Kodaikanal Observatory Bulletin No. LV. The directions in which the different points of the prominence are moving radiate from a point in the chromosphere near − 40°W, indicating a region near this point as the origin of the propelling force.

Measures were also made of the motion radial to the sun of the mean height of the prominence at different latitudes. The rates of ascent were found to be 21 km/sec at 0°W, 40 km/sec at − 10°W, 60 km/sec at − 20°W, 38 km/sec at − 30°W and 35 km/sec at − 40°W, measures in the two last latitudes being possible only in the first three photographs.

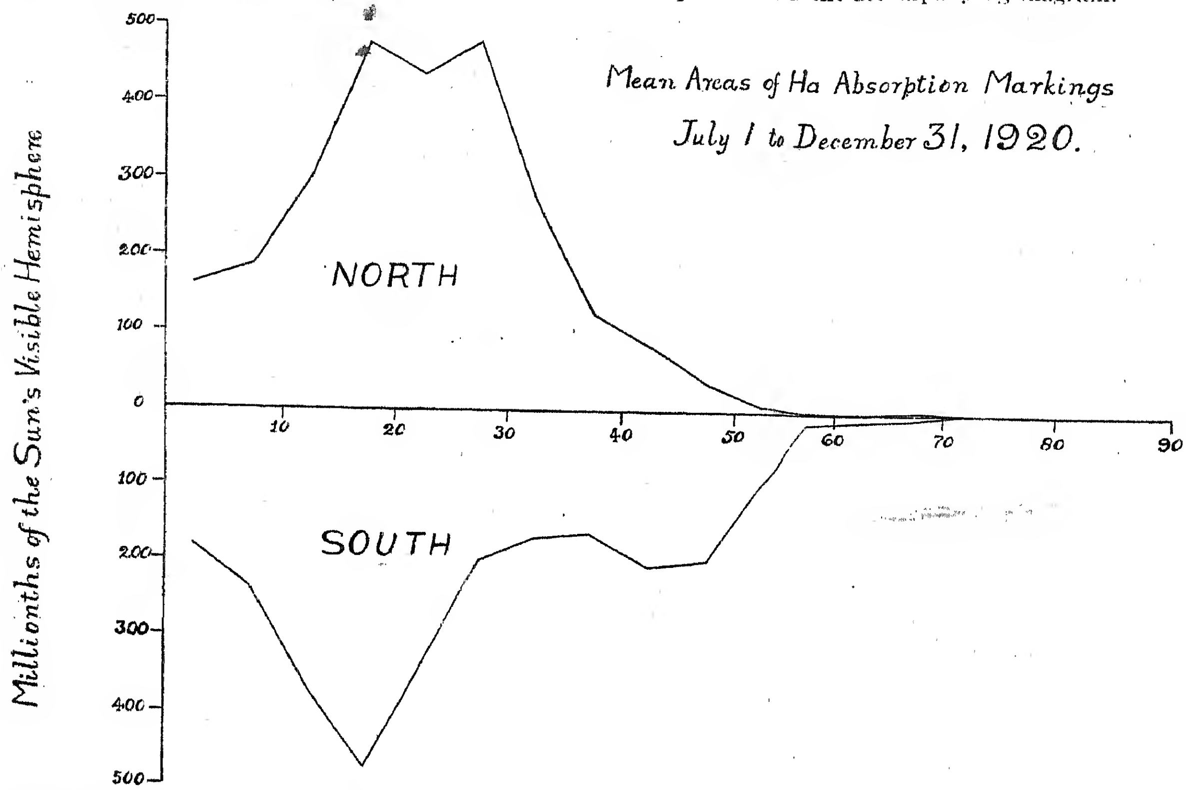
Prominences projected on the disc as absorption markings.

Photographs of the sun's disc in Hα light were obtained on 129 days, counted as 107 effective days. The mean daily areas in millionths of the sun's visible hemisphere corrected for foreshortening, and the mean daily numbers are given below.

	Areas.	Numbers.
North	2597	15·4
South	2661	15·6
Total ...	5258	31·0

These figures represent an increase on the first half of the year of 20 per cent for areas and 21 per cent for numbers; the increase is larger for the northern hemisphere.

The distribution of the mean daily areas in latitude is represented in the accompanying diagram.



The distribution is generally similar to that of prominence areas. Compared with the previous half-year there is less activity near the equator in both hemispheres; in the northern hemisphere there is an increase in a belt from 10° to 40°, and in the southern a decrease from 20° to 40° and an increase from 40° to 50°. These changes from the first half of the year are similar to the changes in prominence areas.

There is again a preponderance of markings at the western side of the central meridian, the percentage east being 46·74 for areas and 49·21 for numbers.

KODAIKANAL OBSERVATORY,
7th February 1921.

T. ROYDS,
Assistant Director.

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